SED

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CONTENTS

CHANGE RECORD 3
LIST OF TABLES 7
LIST OF FIGURES 8
PREFACE 10
ABSTRACT 11
1 INTRODUCTION 12
1.1 Scientific/Technical Background 12
1.2 Experiment Concept 14
1.3 Experiment Objectives 15
1.4 Team Details 15
1.4.1 Contact Point 15
1.4.2 Team Members 16
2 EXPERIMENT REQUIREMENTS AND CONSTRAINTS 22
2.1 Functional Requirements 22
2.2 Performance Requirements 23
2.3 Design Requirements 24
2.4 Operational Requirements 25
3 PROJECT PLANNING 27
3.1 Work Breakdown Structure (WBS) 27
3.1.1 Subsystem Tasks 28
3.2 Schedule 29
3.3 Resources 31
3.3.1 Manpower 31
3.3.2 Budget 32
3.3.3 Educational support 35
3.3.4 Financial support. 37
3.3.5 Analysis and testing support facilities: 38
3.4 Outreach Approach 39
3.5 Risk Register 39
4 EXPERIMENT DESCRIPTION 44
4.1 Experiment Setup 44
4.2 Interfaces 46
4.2.1 Mechanical 46
4.2.2 Electrical 47
4.3 Experiment components 48
4.3.1 Optical Particle Counter (OPC) 48
4.3.2 Diaphragm Pump 49

4.3.3 Air Ion Counters (AICs) 50
4.3.4 Sampling Unit (SU) 51
4.4 Mechanical Design 54
4.4.1 Instruments Housing assembly (IHA) 55
4.4.2 Battery Housing Assembly 58
4.4.3 Electronics housing assembly (EHA) 58
4.4.4 Structural analysis (10 g vertical) 59
4.4.5 Structural analysis (5g horizontal) 60
4.5 Electronics Design 63
4.5.1 Devices connected to Micro-controller 63
4.5.2 Stacked board 1: 66
4.5.3 Stacked Sensor Board 2 (SB2) 71
4.5.4 Ethernet Shield 75
4.5.5 Heaters Board (H-Board) 76
4.5.6 Power control unit (PCU) 79
4.5.7 Motion Mind Motor Controller. 83
4.5.8 GPS Adafruit 84
4.6 Thermal Design 85
4.6.1 Thermal model architecture 85
4.6.2 Boundary conditions 87
4.6.3 Solution 87
4.6.4 Results 88
4.6.5 Conclusions 91
4.7 Power System 92
4.7.1 Power Line One overview (PL1) 92
4.7.2 Power lines two and three overview (PL2 + PL3) 94
4.7.3 Power Control Unit (PCU) 98
4.7.4 Safety issues and solutions 99
4.8 Software Design 100
4.8.1 Requirement Analysis 100
4.8.2 Operating modes 100
4.8.3 Software System Architecture 101
4.8.4 Mission States 102
4.8.5 Datagram structure 109
4.8.6 Total data rate 112
4.9 Ground Support Equipment 114
4.9.1 Ground Station Software 114
4.9.2 GSS Communication Protocols 116
4.9.3 On Board Data Handling (OBDH) 117
4.9.4 Failure detection 121
5 EXPERIMENT VERIFICATION AND TESTING 123

5.1 Verification Matrix 123
5.2 Test Plan 127
5.2.1 Pump Tests (PT) 127
5.2.2 OPC performance tests 129
5.2.3 Air Ion Counter tests (AICT) 130
5.2.4 Software Tests (ST) 131
5.2.5 General Tests (T) 133
5.3 Test Results 137

6 LAUNCH CAMPAIGN PREPARATION 138
6.1 Input for the Campaign / Flight Requirement Plans 138
6.1.1 Dimensions and Mass 138
6.1.2 Safety Risks 138
6.1.3 Electrical Interfaces 139
6.2 Preparation and Test Activities at Esrange 139
6.2.1 Launch site requirements 139
6.2.2 Flight requirements 140
6.2.3 Preparation of the SU 140
6.3 Timeline for Countdown and Flight 141
6.4 Post-Flight Activities 143
6.5 System Success 143

7 DATA ANALYSIS AND RESULTS 145
7.1 Data Analysis Plan 145
7.1.1 Atmospheric data analysis 145
7.1.2 Sample analysis 145
7.2 Launch Campaign 149
7.3 Results 149
7.4 Lessons Learned 149

8 ABBREVIATIONS AND REFERENCES 150
8.1 Abbreviations 150
8.2 References 152
Appendix A Experiment Reviews 154
Appendix B Outreach and Media Coverage 161
Appendix C Gantt chart 167
Appendix D Thermal design details 170
Appendix E Communication protocols 173

LIST OF TABLES

Table 2.1-1 Functional requirements 22
Table 2.2-1 Performance requirements 23
Table 2.3-1 Design requirements 24
Table 2.4-1 Operational requirements 25
Table 3.3-1 Manpower per week 31
Table 3.3-2 Manpower year 31
Table 3.3-3 Budget 32
Table 3.3-4 ESA as Sponsor 34
Table 3.3-5 Sponsorship table 34
Table 3.5-1 Risk Register 40
Table 4.3-1 Experiment summary table 48
Table 4.3-2 LOAC specifications 48
Table 4.3-3 AIC specifications 50
Table 4.4-1 Mechanical Components 54
Table 4.4-2 Structural analysis' summary 59
Table 4.5-1 Sensors communications protocol 65
Table 4.5-2 Other devices communications protocol 65
Table 4.5-3 SB1 Sensors and Instruments connected. 66
Table 4.5-4 Motor Controller features 84
Table 4.5-5 GPS features 84
Table 4.6-1 Critical components' range 85
Table 4.6-2 Node numbering and architecture 171
Table 4.6-3 Node Properties 172
Table 4.6-4 List of materials 172
Table 4.7-1 Power line one (PL1) 92
Table 4.7-2 Power line two (PL2) 94
Table 4.7-3 Power line three (PL3) 94
Table 4.7-4 PL1 overview 97
Table 4.7-5 PL2 + PL3 overview 97
Table 4.8-1 Pre-launch state 103
Table 4.8-2 Idle state 104
Table 4.8-3 Climb state 105
Table 4.8-4 Sampling setup state 106
Table 4.8-5 Sampling state 107
Table 4.8-6 Descent state 108
Table 4.8-7 Datagram structure 109
Table 4.8-8 UPLINK COMMAND datagram 109
Table 4.8-9 DOWNLINK ACK datagram 110
Table 4.8-10 DOWNLINK REQUEST CONFIRM datagram 111
Table 4.8-11 UPLINK RESPONSE datagram 111
Table 4.8-12 DOWNLINK datagram 111
Table 4.8-13 Total data-rate 112
Table 4.9-1 Legend 123
Table 5.1-1 Verification matrix 123
Table 5.2-1 Software test 2 ..... **Errore. Il segnalibro non è definito.**
Table 6.1-1 Electrical interfaces applicable to BEXUS 139
Table 6.3-1 Pre-flight operations 141
Table 6.3-2 Flight sequence 141

LIST OF FIGURES

Figure 3.1-1WBS 27
Figure 3.1-2 Tasks I 28
Figure 3.1-3 Tasks II 29
Figure 4.1-1 Experiment overview 44
Figure 4.1-2 Main scientific instruments 45
Figure 4.2-1 Experiment mounting in M-EGON gondola 46
Figure 4.2-2 Mounting detail 47
Figure 4.2-3 RJF21B mounting 47
Figure 4.2-4 RJF21B socket 47
Figure 4.3-1 LOAC 48
Figure 4.3-2 Boxer 7000 Pump 49
Figure 4.3-3 AIC 50
Figure 4.3-4 Sioutas Impactor 51
Figure 4.3-5 SU overview 53
Figure 4.4-1 Experiment front view 54
Figure 4.4-2 Experiment (side view) 55
Figure 4.4-3 Aluminium Extrusion 55
Figure 4.4-4 Instruments Housing Assembly (top view) 56
Figure 4.4-5 Rubber thickness detail 56
Figure 4.4-6 SU mounting detail 57
Figure 4.4-7 AIC exhaust slit 57
Figure 4.4-8 Battery and Electronic housing assemblies 58
Figure 4.4-9 Von Mises 10 g vertical 60
Figure 4.4-10 Z axis displacement 60
Figure 4.4-11 Von Mises 5 g (x axis) 61
Figure 4.4-12 X axis displacement 61
Figure 4.4-13 Von Mises 5g (y axis) 62
Figure 4.4-14 Y axis displacement 62
Figure 4.5-1 Devices connected to Arduino 63
Figure 4.5-2 Arduino Mega and Pinning scheme 64
Figure 4.5-3 Stacked Board 1 (SB1) 66
Figure 4.5-4 Stacked board SB1 schematics part 1 67
Figure 4.5-5 SB1 part 2 schematics 68
Figure 4.5-6 Humidity sensor schematics 69
Figure 4.5-7 Pressure sensor schematics 69
Figure 4.5-8 Temperature sensor schematics 70
Figure 4.5-9 AIC offset closer 70
Figure 4.5-10 Stacked Sensor Board 2 (SB2) 71
Figure 4.5-11 SB2 schematics pt. 1 72
Figure 4.5-12 SB2 schematics pt. 2 73
Figure 4.5-13 Data Logger schematics 74
Figure 4.5-14 ADC schematic and signal conditioning circuit 74
Figure 4.5-15 Paralleled solid-state relays' schematics 75
Figure 4.5-16 GPS level translator 75
Figure 4.5-17 Arduino Ethernet Shield 76
Figure 4.5-18 Heaters Board (H-Board) 76
Figure 4.5-19 Logical block of H-Board 77
Figure 4.5-20 Control block of H-Board 78
Figure 4.5-21 PCU voltage converting block 79

Figure 4.5-22 PCU Switch and Current-limiting block 81
Figure 4.5-23 PCU Board 82
Figure 4.5-24 Ground scheme 83
Figure 4.5-25 M-M Motor Controller 83
Figure 4.5-26 GPS Adafruit 84
Figure 4.6-1 Thermal Node structure 86
Figure 4.6-2 Worse Hot case 2 90
Figure 4.6-3 WHC1 90
Figure 4.6-4 WHC + cooling due to airflow 91
Figure 4.7-1 PL1 consumption profile 93
Figure 4.7-2 Consumption profile for PL2 and PL3 96
Figure 4.7-3 A5 battery pack 97
Figure 4.7-4 Logical scheme of the PCU board 98
Figure 4.7-5 Logical scheme Heaters' board. 99
Figure 4.8-1 Pre-launch state 103
Figure 4.8-2 Idle state 104
Figure 4.8-3 Climb state 105
Figure 4.8-4 Sampling setup state 106
Figure 4.8-5 Sampling state 107
Figure 4.8-6 Descent state 108
Figure 4.8-7 Bandwidth requirement related to altitude and mission time 113
Figure 4.9-1 GSS interface preliminary design 114
Figure 4.9-2 GS message receive behaviour 115
Figure 4.9-3 GS message transmission behaviour 116
Figure 7.1-1 SEM setup at BIGEA laboratory 146
Figure 7.1-2 PIXE setup at INFN-Legnaro 147
Figure 7.1-3 Germanium detectors at ERL 148
8.2-1 Preliminary Logo 161
8.2-2 Final Logo 162
8.2-3 Other Outreach 162
8.2-4 A5-Unibo Website 163
8.2-5 A5-Unibo Facebook 163
8.2-6 A5-Unibo Twitter 164

PREFACE

A group of students, from the department of Aerospace Engineering, Environmental Science, an Informatics Engineering of the University of Bologna, has been selected to carry out an experiment to monitor the stratosphere. In particular, the proposed experiment, A5-Unibo (Advanced Atmospheric Aerosol Acquisition and Analysis), aims to deepen the knowledge of stratospheric aerosols and reveal some aspects which are not clear in the process of cloud formation.

This experiment was proposed in the framework of the BEXUS programme that allows students from universities and higher education colleges across Europe to carry out scientific and technological experiments on stratospheric research balloons. Each year, two balloons are launched, carrying up to 12 experiments designed and built by student teams.

The REXUS/BEXUS programme is realised under a bilateral Agency Agreement between the German Aerospace Centre (DLR) and the Swedish National Space Board (SNSB). The Swedish share of the payload has been made available to students from other European countries through a collaboration with the European Space Agency (ESA). EuroLaunch, a cooperation between the Esrange Space Centre of SSC and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles. Experts from DLR, SSC, ZARM and ESA provide technical support to the student teams throughout the project. And BEXUS are launched from SSC, Esrange Space Centre in northern Sweden.

ABSTRACT

A5 is a scientific experiment whose aim is to study the microphysical processes involved in cloud formation.

It will fly on the 18th BEXUS balloon that will be launched from Kiruna (SWE) at the end of October 2014.

The experiment consists mainly in two different phases:

The first one is the in-situ measurement of key parameters involved in cloud formation such as particles' size distributions, humidity, temperature, and pressure. In addition to these parameters also ion densities will be measured, in order to assess if a link between ionization rates and cloud formation can be found. All these data will be associated to a specific height and location in order to create detailed vertical profiles.

The second is the collection of Stratospheric Aerosols that will be performed with the use of sampling filters. These samples will then be recollected and analysed in laboratory to gather information about aerosol's composition and properties.

Some of the above mentioned measurements will require the development of brand new instruments and designs, seen the incapacity of commercial ones to work properly in the harsh stratospheric environment. In particular a great effort will be put into the development of a tailored Optical Particle Counter capable of working in micro-pressure conditions and of detecting particles down to 0.3 µm.

Our hope is to be able to create detailed vertical profiles for Particle size distributions and the other key parameters that could be used as a reference for future experiments. We are aware of the fact that, to follow the whole nucleation process, other (bigger and more expensive) instruments, such as Aitkin-Nuclei Counters, would be needed in order to detect particles with sizes lower than 0.3 µm.

Nonetheless we believe that the development of this new balloon-borne design could provide the basis for future applications, since it employs a multi-instrument acquisition approach that could be duplicated even in higher budget missions.

1 INTRODUCTION

1.1 Scientific/Technical Background

Aerosols are solid or liquid particles suspended in the air.

They can come from a wide range of sources, both natural, such as volcanoes, sea foam or dust, as well as from anthropogenic sources such as combustion (e.g. transportation, heating, energy production, industry etc.); particles have a size range from few nm to hundreds of µm.

The effects of their presence in the atmosphere can be divided into direct and indirect effects.

The direct effect is the effect that aerosols themselves exert on the radiative balance of the Earth through a combination of scattering and absorption of radiation. The interaction of aerosol particles with the solar radiation depends on their size, shape, and chemical composition. Some components of the aerosol can scatter solar radiation reducing its flux to the Earth's surface, and are thus capable of reducing the heating caused by greenhouse gases (for example, sulphate). Other components, such as elemental carbon, have a continuous absorbing effect that extends to the IR, and can contribute to the heating effect. The global Radiative forcing caused by this effect (the change in solar Irradiance with respect to 1750) results from the balance of positive forcing mainly due to "black carbon" absorption of solar radiation and a negative forcing of reflecting aerosols, and is estimated to be -0.5 Wm^{-2} [±0.40], which means an overall cooling effect [1].

The indirect Effect is the role that aerosols exert on radiative balance due to their interaction with clouds. In fact, cloud formation itself relies on the presence of aerosols that act as nuclei for condensation of water vapour. Moreover the abundance of aerosols influences some key features of clouds such as their Albedo and lifetime.

In a cloud of constant liquid water content, a greater number concentration of aerosol particles leads to a greater number of smaller cloud droplets which leads to an enhanced reflection of solar radiation (due to increased surface area of the droplets) and hence an increased cloud albedo.

This effect is called "Cloud Albedo effect" or "Twomey effect".

The second indirect effect relates to the lifetime of clouds. An increase in the number concentration of aerosol particles leads to a greater number of smaller cloud droplets and hence reduces the precipitation efficiency of the cloud as smaller droplets take longer to grow to a size needed to precipitate out. This increases the lifetime of the cloud, and hence also its reflectivity over time [2].

These indirect effects are difficult to evaluate, since the microphysical processes involved in cloud formation are not completely understood.

However a net radiative forcing is estimated to be around -0.70 Wm^{-2} [-1.1, +0.4], and from this result it is clear that there is still a big uncertainty in the estimation of this effect.

Another factor that is believed to affect cloud formation is the **ionization** of atmospheric particles caused by Cosmic Rays. This proposal stems from an observed correlation between cosmic ray intensity and Earth's average cloud cover over the course of one solar cycle that was first reported by Svensmark and Friis-Christensen in 1997 [3].

The observed variation of low clouds by about 1.7% absolute corresponds to a change in Earth's radiation budget of about 1 Wm^{-2} between solar maximum and minimum, which is highly significant when compared, for example, with the estimated radiative forcing of 1.4 Wm^{-2} from anthropogenic CO_2 emissions.

The main mechanism that is believed to link ionization and cloud formation is the so called **"Ion aerosol clear air mechanism"** [4]: aerosols responsible for Cloud Droplets (CD) formation can be directly injected into the atmosphere (e.g., volcanic eruptions or pollution) or created from trace condensable vapours in the atmosphere itself. In the latter case ionization of gases can lower the nucleation barrier and hence increase the formation rate of UCN (Ultrafine condensation nuclei) that can eventually grow into CCN (Cloud condensation nuclei), which are aerosols with sufficient diameter (typically >0.1 μm) to act as nuclei for CD formation.

Besides enhancing nucleation, charged aerosol particles resulting from CR ionization can also grow more quickly than uncharged particles owning to the enhanced condensation rate of polar molecules.

These two effects combined together suggest that this mechanism has an outcome quite similar to the Aerosol-indirect effect, in the sense that it helps the formation of more smaller particles increasing cloud reflectivity and lifetime, but has two major differences: it acts on a global scale, is not spatially limited to polluted regions, and can act on different time scales, since CR fluxes vary not only through a solar cycle but on centennial and millennial time scales.

Recent measurements by an airborne ion mass spectrometer in the upper troposphere showed large positive-ion clusters and recent observations in the Upper Troposphere and Lower stratosphere have shown high concentrations of UCN's (from 4 to 9 nm) that indicate very recent particle formation, consistent with numerical simulations for Ion Induced Nucleation (IIN) [5].

The search for a link between CR's and Cloud formation is also one of the main drivers for the CLOUD experiment conducted at CERN since 2009, where a chamber filled with atmospheric gases is crossed by charged pions that simulate ionizing CR's. Some preliminary results suggest that indeed IIN is a relevant factor to determine nucleation rates in the upper troposphere [6].

1.2 Experiment Concept

The experiment we suggest has the advantage of covering a wide range of topics related to cloud formation. We will mount an Optical Particle Counter (OPC) that uses back-scattered radiation of a laser diode to measure particle densities and size distribution of aerosols throughout the whole troposphere and stratosphere, with a size range from 0.3 µm to 100 µm.

Thanks to the slow ascending speed of the BEXUS balloon and the short sampling time of the OPC we will be able to create detailed vertical profiles for particulate matter (and also CCN's and CD's).

In parallel to particle size distributions, also ion densities (both positive and negative) will be measured throughout the flight with Air Ion Counters, leading to the creation of vertical profiles.

In this way we hope to be able to create a link between ionization rates and CCN's density.

Moreover, once reached the nominal altitude in the stratosphere, we will perform an in-situ collection of aerosols with the use of a diaphragm pump. This pump will create an airflow through a special collector called Sioutas Impactor that owns the big advantage of sorting the sampled particles by their mass and size, making post-flight analysis much easier with respect to normal filters.

This experiment design therefore combines the collection of aerosols, following the footsteps of previous experiments such as DUSTER [7] or “Stratospheric Census” [8], to the direct in-situ analysis of particle distributions as the ones performed by other balloon-borne experiments, studying both the direct effects of aerosols by analysing their chemical composition, and the indirect effects related to cloud formation.

1.3 Experiment Objectives

Primary Objectives

1. To create detailed vertical profiles for Particle size distributions and Ion densities throughout Troposphere and Stratosphere.
2. To study the microphysical processes behind cloud formation, combining these data with key atmospheric parameters such as temperature, humidity and pressure.
3. Investigate the correlation between cosmic-rays, ionization and nucleation rates.

Secondary Objectives

1. To retrieve aerosol samples and make them available for laboratory post-flight analysis (in particular, PIXE, SEM, γ-spectrometry)
2. To analyze the samples determining aerosols' chemical composition and morphology
3. To create a reliable yet simple concept for future atmospheric measurements

1.4 Team Details

1.4.1 Contact Point

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1.4.2 Team Members

Encarnaciòn Serrano Castillo (Team Leader and System Engineer)

Encarnación was born in Madrid in 1988. She took her bachelor and master degree in Aerospace Engineering in the Polytechnic University of Madrid. In 2011 she went to Italy with a Students Exchange program called ERASMUS. She was interested in the work that Flight Mechanics Laboratory was developing, so she stayed in Italy for her Master Thesis project: " Quadrotor modelling and data fusion complementary filter" she had the opportunity to study the dynamics, to integrate sensors and acquire the data for the attitude determination system of a Quadrotor. Now she is a PhD student in Advanced Engineering Science at Bologna University with a project called "Non-linear control for under-actuated systems, atmospheric and space applications" for attitude control. She is the team leader of A5-Unibo selected due to the fact that she has experience in coordinating groups, as logistics coordinator and Educational assistant in ESEO (European Students Earth Orbiter) programme.

Encarnación in responsible for the project management the project planning, the communication with sponsors and economical management and part of the outreach of this project. She is also system engineer and due to her background she will give support to the electric and electronic subsystems and sensor interfaces and testing.

Alberto Sodi (System Engineer)

He has completed his BSc in Aerospace Engineering at Bologna University with a Thesis in Control Theory, entitled: “Modelling and Control of an Extended Formation with Behavioural Approach”. He is now earning his MSc in Aerospace Engineering at Bologna University.

Alberto is responsible for the supervision of the project and the analysis and prevention of each possible risk.

Igor Gai (Ground Station)

Igor was born in Borgo Maggiore (SMR) in 1991. He lives in Torraccia, in the small Republic of San Marino. He graduated in 2013 at University of Bologna, in Aerospace Engineering (Bachelor’s) with the thesis “Design and implementation of a control and remote management device for a satellite tracking system (ALMA-Tracker)”.

He also did a previous internship using LabVIEW on a Compact-RIO system for data acquisition and processing. He is now attending Aerospace Engineering Master Degree at University of Bologna.

Concerning A5, Igor is developing Ground Station SW and he is mostly involved in the software design.

Danilo Boccadamo (Power)

Danilo was born in Rimini in 1991. He lives in San Clemente, a small town near Rimini. He is a bachelor student in "Aerospace Engineering".

At the moment he's writing his bachelor thesis on "Dual-Fuel Application in Diesel Motors". For this thesis he was responsible of setting the test bench and the acquisition systems. Furthermore he has as a hobby, static and dynamic modelling.

In A5-Unibo he is responsible for the Power Subsystem

Paolo Lombardi (Mechanics)

Paolo, has completed his BSc in Aerospace Engineering at Bologna University, and he is currently studying for the Master Degree in Aerospace Engineering at Bologna University.

Paolo is responsible for the Mechanical design of A5.

Alice Zaccone (Software)

Alice was born in Rimini in 1991, a small city in the centre of Italy. Alice studied Aerospace Engineering as an undergraduate at the University of Bologna, and is now studying to take the Master degree in Aerospace Engineering. For her bachelor thesis she worked on a project for the analysis of the atmospheric gasses. The system was composed of an array of gas sensors controlled with a microprocessor and she developed a software for data acquisition and transmission to ground.

Alice is responsible for the configuration and control of the ambient sensors.

Abramo Ditaranto (Electronics)

Abramo was born in Matera, in the south of Italy, in 1988. He studied Aerospace Engineering at the University of Bologna and took his bachelor degree in 2010 working on a project which consisted on the creation and the construction of a device for infrared transmission developed for on-board satellite applications.

In A5 Abramo is responsible for the Electronic Subsystem.

Marco Didoné (Thermal)

Marco was born in Castelfranco Veneto in 1990. He lives in a small town called Albaredo in the North-East of Italy. He was graduate at the University of Padua in 2013 with the thesis on “Environmental flux modelling and thermal analysis for MISSUS experiment on stratospheric balloon BEXUS” and now he is a Master student in “Aerospace Engineering” at the University of Bologna. He played basketball for ten years and at present he plays the bass guitar for a rock band.

Concerning A5-Unibo experiment, Marco is responsible for the Thermal design.

Elisa Luconi (Sample Analysis)

Elisa was born in Chiaravalle (Ancona) in 1989. She took her bachelor degree in Environmental Science at the University of Bologna in 2012. During a stage in the INGV (National Institute of Geophysics and Volcanology) in Bologna, she wrote her thesis titled “Interaction between hurricanes and phytoplankton blooms in the Atlantic Ocean”.
Now she’s earning her Master Degree in Science and nature management at the University of Bologna
In A5 she will be responsible for the post-flight data analysis of the collected sample.

Riccardo Lasagni Manghi (Verification and Testing)

Riccardo was born in Reggio Emilia in 1990. He took his Bachelor degree in Astronomy at the University of Bologna with his final thesis on “Virial Theorem and its Astrophysics applications”. During summer of 2013 he attended the “Alpbach Summer School” organized by ESA, where he took active part in the development of the “Pacman” mission. After this experience he decided to apply for the Master degree in Aerospace Engineering in Bologna where he is currently studying.

In A5 he will be responsible for the writing of the SED documentation and for the Testing and Verification process.

Erika Brattich (Data Analysis)

Erika was born in Genova (Italy) in 1984. Nowadays she lives in a small town called Ravenna in the North-East of Italy, 80 km far away from Bologna. She got her bachelor in Atmospheric Physics and Meteorology at the University of Bologna in 2003 with the thesis “Techniques of data analysis and measurements in the Bologna area”. She graduated in Physics at the University of Bologna in 2010 with the thesis “Composition of atmospheric particulate matter in Bologna: Application of receptor modelling”. Now she obtained her PhD degree in Environmental and Geological Sciences at the University of Bologna (dissertation thesis to be discussed in April 2014) with the thesis “Origin and variability of PM10 and atmospheric radiotracers at the WMO-GAW station of Mt. Cimone (1998-2011) and in the central Po Valley”. Meanwhile, since February 2014 she is assistant research fellow at the University of Bologna. Concerning A5-Unibo experiment, Erika is responsible of the scientific and theoretical analysis of the experiment.

Luca Mella

Luca was born in Cesena in 1988. He worked a few years in the ICT industry before starting his studies in Computer Engineer at University of Bologna in 2008. He actively participated in several off-lecture initiatives and began to coordinate the CeSeNA Security group in 2010, a Unibo study group which takes part in security competitions around the world (aka Capture the flag). Luca took his bachelor degree in fall 2011 with the thesis “Rilevamento di attacchi di rete attraverso protocolli di monitoraggio per router IP” and continued his studies with a Master on Computer Engineering at University of Bologna. During this time, he had the opportunity to study and work on several challenging topics like computer vision, distributed systems and embedded systems. He took his master degree in spring 2014 with the thesis “ICT Security: Testing methodology for targeted attack defence tools”.

Concerning A5 Luca contributes to the design and the development of the software systems and communications.

Mattia Baldani

Mattia was born in Urbino in 1989. He lives in Carpegna, a small town near Rimini. He took his bachelor degree in Computer Engineering at the University of Bologna in 2012. He has experience in the development of large distributed networked systems, embedded system design and programming. Concerning A5 Mattia contributes to the design and the development of the software systems and communications.

Svetlozar Orlovski

2 EXPERIMENT REQUIREMENTS AND CONSTRAINTS

2.1 Functional Requirements

See also Verification Matrix in chapter 5

Table 2.1-1 Functional requirements

Ref	Requirement
FR1	The experiment shall measure particles' size distribution outside the gondola during the whole flight
FR2	The experiment shall measure ion densities outside the gondola during the whole flight.
FR3	The experiment should measure outside ambient temperature during the whole flight.
FR4	The experiment shall measure outside ambient pressure during the whole flight.
FR5	The experiment should measure outside ambient relative humidity during the whole flight
FR6	The experiment shall collect aerosol samples drawing air from outside the gondola during the floating phase in the stratosphere and make them available for post-flight analysis
FR7	The experiment shall keep track of its absolute position throughout the flight, in order to relate the collected data to a particular height and coordinate
FR8	The experiment shall measure the temperature inside the gondola in order to ensure the operational range of the instruments is not exceeded.
FR9	The experiment should measure the rate of air flow through the pump for the whole duration of the sampling phase
FR10	The experiment shall save all the measured quantities on an internal SD
FR11	The experiment shall relay all the measured quantities to ground

2.2 Performance Requirements

Table 2.2-1 Performance requirements

Ref	Requirement	From
PR1	Measurements for particles' size distribution shall be made at a rate of at least 1 measurement every 20 s, corresponding to a vertical resolution of 80-100 m, given the average ascending speed of 4-5 m/s	FR1
PR2	Measurements for ion densities shall be made at a rate of at least 1 measurement every 20 s, corresponding to a vertical resolution of 80-100 m, given the average ascending speed of 4-5 m/s	FR2
PR3	The temperature measurements outside the balloon should be possible in a range between -90 and +30 °C	FR3
PR4	The temperature measurements outside the balloon should be made with an accuracy of ±0.2 °C	FR3
PR5	The pressure measurements shall be possible in a range between 5 and 1100 mbar	FR4
PR6	The pressure measurements shall be made with an accuracy of ± 1 mbar	FR4
PR7	The humidity measurements should be possible in a range from 0% to 100% RH	FR5
PR8	The humidity measurements should be made with an accuracy of ±2%	FR5
PR9	The pump shall suck a nominal flow rate of 9 l/min at stratospheric conditions in order to maximize the efficiency of the collecting filter (more details given later)	FR6
PR10	The altitude shall be measured with an accuracy of at least ±40 m	FR7
PR11	The coordinates shall be measured with an accuracy of at least ±40 m	FR7
PR12	The temperature measurements inside the gondola shall be possible in a range from -20º to 50º.	FR8
PR13	The temperature measurements inside the gondola shall have an accuracy of ±1 °C	FR8

2.3 Design Requirements

Table 2.3-1 Design requirements

Ref	Requirement
DR1	The experiment shall withstand vertical loads of 10 g and horizontal loads of ±5 g
DR2	The experiment should withstand landing shocks of up to 35g.
DR3	The experiment shall be able to operate while exposed to outside temperatures down to -15°C for the whole duration of pre-flight phase.
DR4	The experiment shall be able to operate while exposed to outside temperatures down to -80°C for the duration of the flight.
DR5	The experiment (and in particular the SD) shall withstand storage temperatures down to -15°C for the duration of the recovery procedures (up to 48 hours)
DR6	Integrity of samples shall be guaranteed in case of water landing
DR7	On the outside of the experiment housing, a 4 pin connector type MIL-C-26482P series 1 connector shall be installed in order to access the gondola's power bus
DR8	The experiment batteries shall be qualified for use on a BEXUS balloon
DR9	The experiment batteries shall either be rechargeable or shall have sufficient capacity to run the experiment during pre-flight tests, flight preparation and flight.
DR10	The batteries in the gondola-mounted experiment should be accessible from the outside within 1 minute
DR11	The experiment housing shall be supplied with a sufficient number of brackets or a bottom rail plate to facilitate safe mounting of the experiment.
DR12	The experiment housing shall have mounting provision to interface on to M-EGON gondola
DR13	A panel mounted connector for the E-Link of the type Amphenol RJF21B must be used
DR15	Components that can represent a possible hazard for the recovery team (OPC's laser and batteries) shall be marked with a specific danger sign. (more details given in chapter 6)
DR16	All components used for the collection of aerosol samples shall be clean to ensure that particles collected are stratospheric rather than contamination
DR17	The pore size of the aerosols' collecting filters shall be 0.5 μm, to ensure collection of small particles

DR18	A sealing barrier shall be used to ensure that the components used for the collection of aerosol samples remains clean during assembly, testing and integration
DR19	A blank control sampling filter shall be added, identical to the sample holder, to monitor the environment during pre-launch, launch and flight and assess any possible contamination
Software requirements	
SR1	SW shall be compatible with HW
SR2	SW shall not crash in case of error/Handle failure
SR3	SW shall monitor running time of each loop and eventually interrupt it (avoid delays in running time)
SR4	SW shall restart in case of failure (not be compromised in case of power loss)
SR5	SW shall not be locked in manual mode in case of data link loss
SR6	SW shall continue to work correctly in case of failure of some devices
SR7	SW shall store all collected data without any losses
SR8	SW shall not overwrite or corrupt stored data
SR9	SW shall use redundant data in the determination of descending phase start, meaning rely both on GPS and pressure data to determine descending rate but also request GS ACK
SR10	SW shall comply with E-Link and TCP/IP specification
SR11	SW shall not fail in case of GS connection failure and manage to reconnect
SR12	SW shall not to be crashed by GS command errors
SR13	GSS shall receive, display and log data
SR14	GSS shall allow user to set commands to on-board software

2.4 Operational Requirements

Table 2.4-1 Operational requirements

Ref	Requirement
OR1	The experiment shall be able to function autonomously in the event that contact with Ground is lost.
OR2	Piping materials and parts of the instruments coming out of the experiment shall be protected with a *remove before flight* cover
OR3	*Remove before flight cover* shall be removed before flight
OR4	The experiment shall autonomously open the pinch valves and unseal

	the sampling filter once reached the nominal altitude in the stratosphere.
OR5	The experiment shall autonomously close the pinch valves and re-seal the sampling filter prior to the descent
OR7	The experiment shall be turned off prior to entering the descending phase (Pump, AIC's and OPC should be disabled)
OR8	The amount of Offset for the AIC's shall be measured prior to the flight and it shall not be higher than ± 100 mV

3 PROJECT PLANNING

3.1 Work Breakdown Structure (WBS)

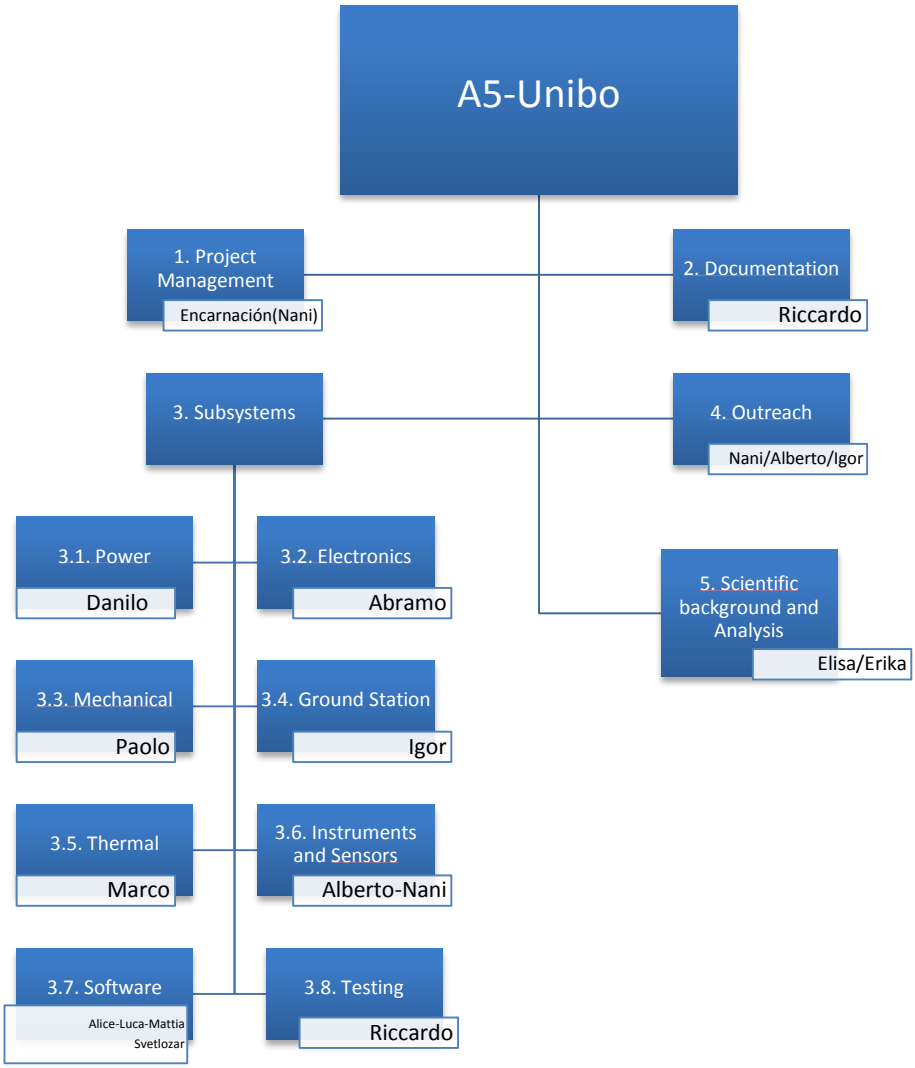

Figure 3.1-1WBS

3.1.1 Subsystem Tasks

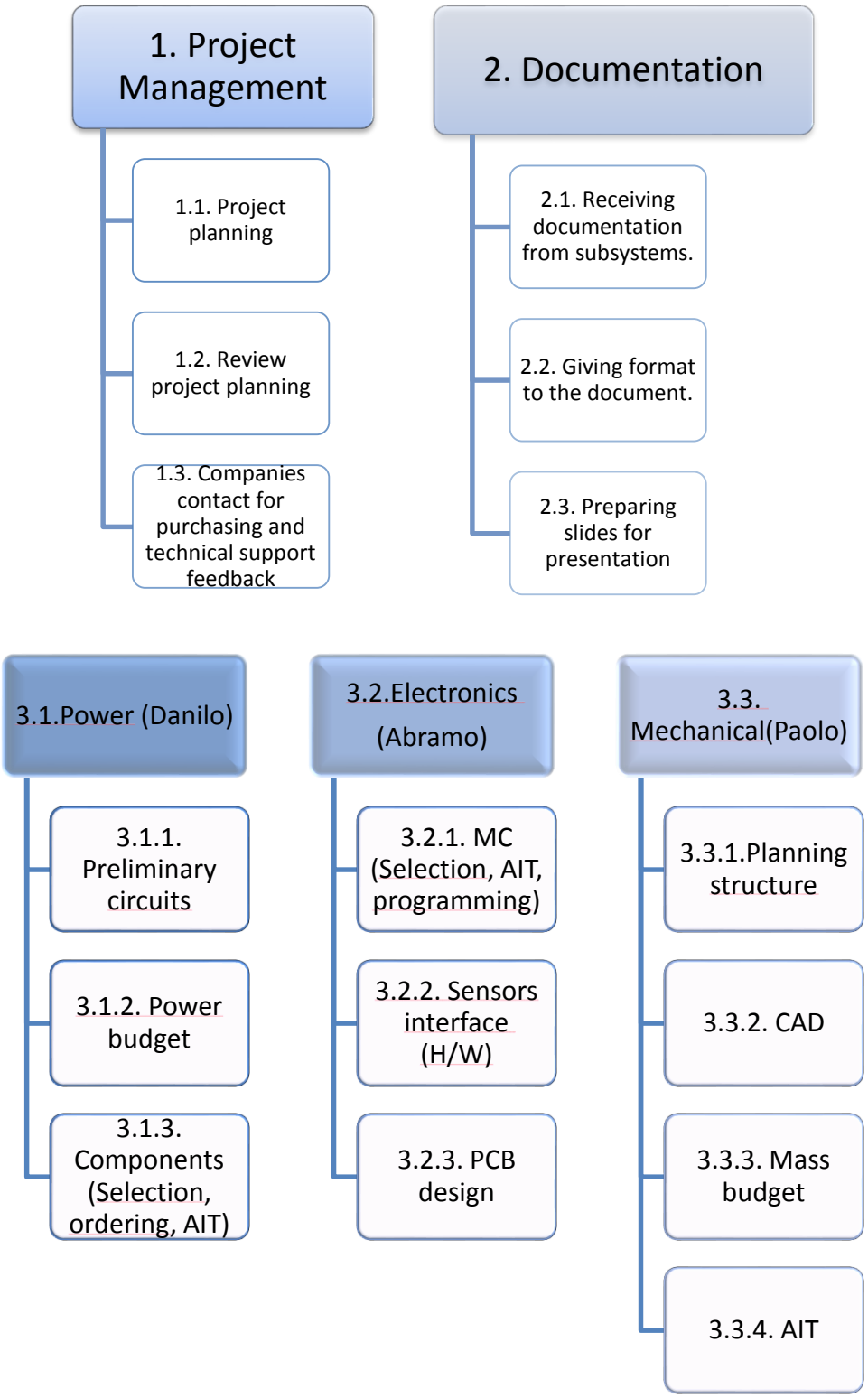

Figure 3.1-2 Tasks I

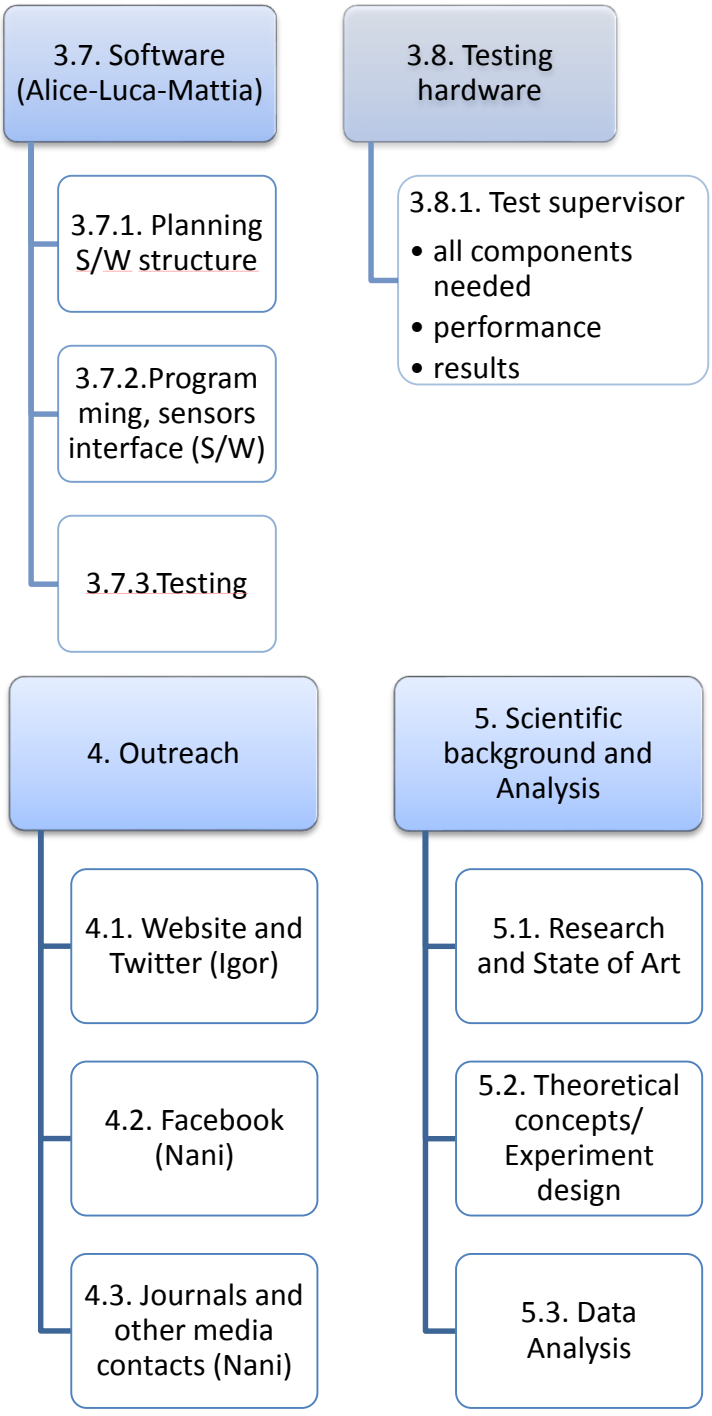

Figure 3.1-3 Tasks II

3.2 Schedule

Once A5-Unibo was selected the tasks were defined in depth. Every task is managed by a responsible assigned in order to cover all the parts of the project.

The Gantt chart (see appendix C) gives a general estimation of the overall project duration. The chart is updated weekly with the project progresses. In the meetings every team member explains the work done during the week. Every single member is also part of a working sub-team where all the information is shared deeply. In this way we would like to avoid possible vacancies in the subsystems. If any member has to leave the team, other two or three members could take care of his/her work in order to not stop the progress of the project.

Sub-team 1: Electronics and Power (Nani, Danilo, and Abramo)

Sub-team 2: System, Test and Mechanics (Nani, Paolo, and Riccardo)

Sub-Team 3: Software and ground station (Alice, Luca, Mattia, Svetlozar and Igor)

Sub-Team 4: Outreach (Igor, Nani, and Riccardo)

Sub-Team 5: Scientific (Riccardo, Elisa, and Erika)

Sub-Team 6: Sensor Interfaces (Nani, Alice, and Abramo)

Sub-Team 7: Project Management, Documentation (Nani and Riccardo)

At the moment most of the tasks are being developed on time although some new tests have been added and the dates of some others have been modified because shipping delays of key components for tests. In Gantt chart it is also highlighted the current progress with a vertical red line As it can be seen we have some delays in the power subsystem due to the selection of a different model of batteries after CDR recommendations. The mechanics subsystem has some delays in the acquisition of the components and consequently in testing due to the change of the design because of the change of OPC that is now substituted by LOAC. But the structure beams and connectors are already in laboratory and the structure is being manufactured.

Regarding the electronics, the design of the PCB and PCU has been finished and is ready to be sent for manufacturing.

The software team has one new member (Svetlozar) that has been selected in order to complete and support the Software & GS subsystem team. The software subsystem has improved a lot and they are ahead of schedule. The thermal subsystem has finished the software modelling and is waiting for heaters acquisition for testing.

Regarding the secondary objective, thus taking samples of aerosol, A5unibo has performed many tests in order to interface in a correct way the particular characteristics of one instrument, Sioutas that require an specific air flow from

the pump that must be controlled by a motorcontroller. This tests are taking more time than initially foreseen.

The purchasing and delivering of components are the leading causes of delay during this phase of the project.

3.3 Resources

3.3.1 Manpower

Depending on the availability of each team member we define the table 3.3-1.

Table 3.3-1 Manpower per week

Team Member	Hours per Week
Nani	16
Alberto	16
Riccardo	16
Paolo	12
Elisa	8
Abramo	12
Igor	12
Danilo	12
Marco	12
Alice	12
Erika	8
Luca	12
Mattia	12
Svetlozar	12

Table 3.3-2 Manpower year

Name of Team Member	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J
Nani															
Riccardo															
Alberto															
Paolo															
Igor															
Danilo															
Alice															
Abramo															
Marco															
Erika															

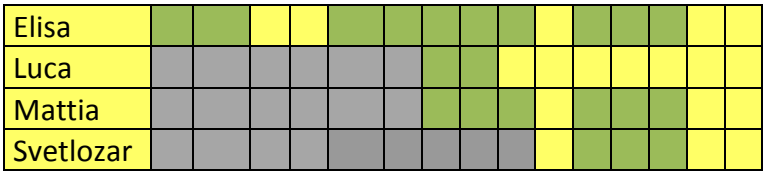

Table 3.3-2 shows the availability of each team member during the year. The colours code is: Green (more than 70% of the time), Yellow (between 30 and 70%) and red (Less than 30%) where 100% is defined as 16 hours per week. In grey the months of no participation in BEXUS programme.

Months of the project are shown in orange for 2013, in blue for 2014 and in pink for 2015.

3.3.2 Budget

Table 3.3-3 Budget

Components	Price €	Amount	Total €	Support	Status
Arduino Ethernet Shield	33,17	1	33,17	FML	Present
Arduino Mega 2560	41,56	1	41,56	FML	Present
Micro SD Shield	22,97	1	22,97	FML	Present
Motion Mind Motor Controller	95,77	1	95,77	FML	Present
Micro SD card	8	2	16	FML	Present
ADC (18bit I2C)	2,75	4	11	FML	Present
Relay 5A 5V	1,11	5	5,55	FML	Present
Batteries Li-Po SAFT	530 125	2	1185	FML	Ordered – Looking for sponsors
RS232 to TTL Converter	2,81	2	5,62	FML	Present
Air Ion Counters	550	2 (1 free)	550	FML	Present
LOAC (OPC)	4900	1	4900	FML/DEC	Ordered – Looking for sponsors
Particle Counter	2500	1	2500	DEC	Present
Pump (BOXER)	Free	2	Free	BOXER	Present
Electro-valves (and related materials)	175	2	350	FML	Selected – Looking for Sponsor
Temperature sensors DS18B20	4,94	3	14,82	FML	Present

Temperature sensors LM35DZ	1,11	10	11,1	FML	Present
Humidity Sensor HIH9120-021	22,09	2	44,18	FML	Present
LT1110CN8 IC REG BUCK BOOST 12V 0.4A	4,67	3	14,01	FML	Present
Pressure Sensor	2,8	3	8,4	FML	Present
Switching reg. 5V	15,14	2	30,28	FML	Present
Switching reg. Variable	25,68	2	51,36	FML	Present
Beams and plates	75	1	75	FML	Present
Heaters	70	4	280	FML	Selected – Looking for Sponsor
Sioutas	700	1	700	DEC	Lent
GPS "Adafruit"	40	1	40	FML	Present
Header 8 Pin Long	0,35	1	0,35	FML	Present
Header 8 Pin Short	0,31	10	3,1	FML	Present
Header 10 Pin Long	0,5	5	2,5	FML	Present
Header 6 Pin Long	0,35	5	1,75	FML	Present
MOSFET P-CH 12V 2.6A	0,36	10	3,6	FML	Present
LTC4412ES6 Selector	2,78	7	19,46	FML	Present
497-7285-1-ND IC REG LDO 3.3V 0.1A	0,4	5	2	FML	Present
LT3080EST#TRPBFCT-ND	3,56	4	14,24	FML	Present
L7812ABV	0,54	5	2,7	FML	Present
Other IC	90	1	70	FML	Present
Arduino Mega Shield	14,52	4	58,08	FML	Present
Consumables (cables, wire, etc.)	60	1	60	FML	Present
Platforms	60	1	60	FML	Present
Modular Plastic Storage Boxes	7,8	2	15,6	FML	Present
Printed circuit boards (SB1, SB2)	200	3	600	FML	Designed Looking for Sponsor
Power Control Unit	200	1	200	FML	Designed Looking for Sponsor
Launch campaign Travel and accommodation	1500	4	6000	TBD	Looking for Sponsors

Travel and accommodation (CDR)	350	1	350	TBD	Looking for Sponsors
Taxes Robot-Italy	48,65	1	48,65	FML	Paid
Total			18497		

FML: Flight Mechanics Laboratory funds

DEC: Department of Environmental Chemistry

BOXER: Boxer Pumps.

In table 3.3-3 all the components needed for the project are mentioned. The instruments ordered are shown and yellow, while the ones already present in the laboratory are shown in green. The LOAC Optical Particle Counter will be purchased by FML and DEC jointly.

As shown in table 3.3-4, ESA is our biggest sponsor regarding Travel and Accommodation, since it pays for the participation of four team members at every project-related event. The estimated amount sponsored is of 11400 €.

Table 3.3-4 ESA as Sponsor

Description	Price €	Quant.	Total €	Support	Status
Travel and accommodation (PDR)	1000	4	4000	ESA	Sponsored
Travel and accommodation (CDR)	350	4	1400	ESA	Sponsored
Launch campaign Travel and accommodation	1500	4	6000	ESA	Sponsored
TOTAL			11400		

Table 3.3-5 shows a more detailed description of the FML and DEC contribution.

Green cells represent the funds we already have, instruments already purchased, or those that have been donated. The orange cells represent costs that are not covered yet, and for which we are currently looking for sponsors. FML will cover the costs of the components in case we won't find external sponsorship, while a critical issue remains the cost for travel and accommodation for the flight campaign which will have to be covered by the students themselves in case of no sponsorship.

Table 3.3-5 Sponsorship table

Sponsor	FML €	DEC €	€ Total
Electronics Structure Already purchased instruments	3857,82		3857,82
LOAC	1900	3000	4900
Sioutas		Lent	Lent
BOXER PUMPS			Donated
SAFT BATTERIES	1185		1185
SB1, SB1, PCU	600		600
Air Ion Counter	550		550
Travel & accommodation (CDR)			350
Travel & accommodation (Launch Campaign)			6000
Beams	75		75

3.3.3 Educational support

We are mainly supported by Professor **Fabrizio Giulietti,** coordinator and supervisor of Flight Mechanics Laboratory (University of Bologna).

Fabrizio Giulietti

Assistant Professor

ING-IND/03 MECCANICA DEL VOLO (ING-IND/03)

http://www.unibo.it/faculty/fabrizio.giulietti

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Dipartimento di Ingegneria Industriale

Other Contacts

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From the scientific point of view, Professor **Laura Tositti** from Department of **Environmental Chemistry** of the University of Bologna will offer theoretical support and support for the post-flight analysis.

Laura Tositti

Associate Professor

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A5-Unibo would like to thank all the experts that offer their kind help in order to support the team.

From ESTEC:

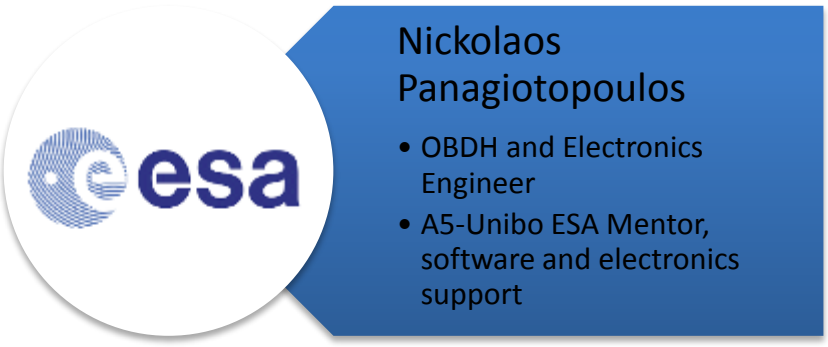


Figure 3.3-4 Nickolaos Panagiotopoulos

From Forlì:

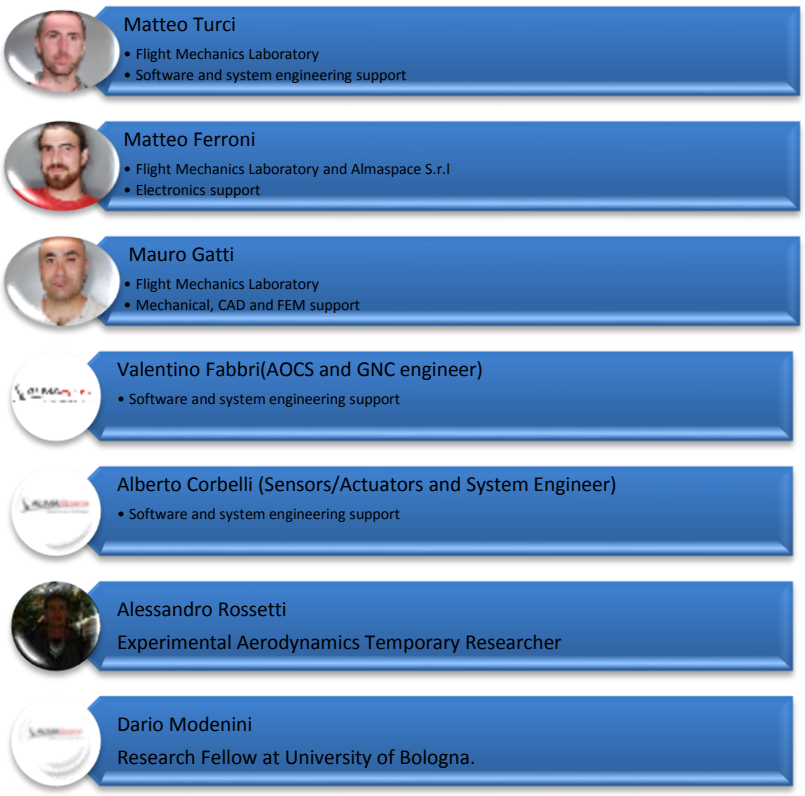

Matteo Turci
• Flight Mechanics Laboratory
• Software and system engineering support
Matteo Ferroni
• Flight Mechanics Laboratory and Almaspace S.r.l
• Electronics support
Mauro Gatti
• Flight Mechanics Laboratory
• Mechanical, CAD and FEM support
Valentino Fabbri(AOCS and GNC engineer)
• Software and system engineering support
Alberto Corbelli (Sensors/Actuators and System Engineer)
• Software and system engineering support
Alessandro Rossetti
Experimental Aerodynamics Temporary Researcher
Dario Modenini
Research Fellow at University of Bologna.

Figure 3.3-5 Support from Forlì

3.3.4 Financial support.

Supervisor's (Fabrizio Giulietti) Research Group funds will cover the experiment costs in case of no external sponsorship.

ESA is A5-Unibo's Sponsor for Travel and Accommodation for four team members.

At the moment, we have these sponsors for the project:

Air Ion Counter

ALPHALAB Inc. – American manufacturer of electronic measuring devices. They offer: Gauss meters, electromagnetic field meters (measured by the strength and polarity of the electromagnetic field), air ion counters, (number of ions per cubic centimetre of air), surface DC voltmeters, electrostatic meters, voltage touch monitors, etc.

Pump

Boxer® Pumps. – Boxer Pumps are used in portable and fixed gas analysers, pipette controllers and many other pressure and vacuum applications.

Structure Manufacturing

I.C.O.S. s.r.l -- I.C.O.S. s.r.l has found in the product and process differentiation its success factor, by the fusion of artisan tradition and technological innovation.

The production is diversified: perforating tubes, prickers and punches for press-knives for footwear leather and paper industries, precision mechanical parts by sub-contracted operations (turning, milling, EDM), metal heels, special horseshoes and precision metal fittings in general.

I.C.O.S. has skills and professionalism, innovative machineries, flexible and complementary production processes to offer the customer a quality service.

Camera

Dogcam -dogcam is the leading UK based design and development company of innovative and rugged bullet video cameras for action sports, recreation and motorsport use.

We are still looking for other institutions and companies that could appreciate our project.

A5-Unibo will be fully cover by FML funds in case of no external sponsorship for all the components needed for the experiment.

The International Relationship Department of the Forlì City Hall is currently studying a proposal we wrote for funding and we expect positive results soon.

3.3.5 Analysis and testing support facilities:

Flight Mechanics Laboratory of University of Bologna. We have the possibility to perform sensor calibration measurements, mechanical and electrical integration of the instruments and software programming and simulations. The assembly of the instruments will be also performed there.

Micro-propulsion Laboratory, where we can performance vacuum chamber tests for our instruments. We can do mechanical tests (vibration) in University of Bologna Hangar facilities.

Dep. of Chemistry "G. Ciamician" (University of Bologna) offers the possibility to analyse the retrieved samples also thanks to their collaboration with external Laboratories:

PIXE Analysis, c/o **Laboratori Nazionali INFN**, Legnaro (PD), Italy, to determine trace elements (11 < Z <92)

SEM Analysis at **BIGEA**, «Dipartimento di Scienze Biologiche, Geologiche ed ambientali», University of Bologna: useful method to observe single particles, to determine their sizes and to identify the sources of emission of particulate matter.

3.4 Outreach Approach

The goal of this activity is to create a link between the general public and the work performed in Flight Mechanics Laboratory, to encourage and motivate people's personal careers. As outreach activities we would like to introduce students from schools, universities and general public to our experiment and other ESA Educational activities and projects.

A5-Unibo team activities will be presented to undergraduate and graduate students of "School of Architecture and Engineering" and "Earth Science" faculties of the University of Bologna in programmed conferences.

We have some contacts with Italian press. La "Repubblica" (Bologna) has published an article about us on the 22nd Jan 2014 titled: "Ingegneri in Svezia per studiare la vita delle nuvole". Emilia Romagna media are very receptive to research and innovation. University of Bologna press is also very interested in our work.

Experiment achievements as well as pictures, current information, new sponsors, details about our daily activities will be shown in Flight Mechanics Laboratory, University of Bologna webpage. You can find it between the research activities. http://www.flightlab.unibo.it/research.htm

Website: http://www.the5f.com/bexus/

Facebook page: https://www.facebook.com/A5Unibo

The scientific results of the experiment will be proposed as a contribution paper in suitable international conferences or journals. For more details see also Appendix B

3.5 Risk Register

Risk ID

TC – technical/implementation

MS – mission (operational performance)

SF – safety

VE – vehicle

PE – personnel

EN – environmental

Probability (P)

A. Minimum – Almost impossible to occur

B. Low – Small chance to occur

C. Medium – Reasonable chance to occur

D. High – Quite likely to occur

E. Maximum – Certain to occur, maybe more than once

Severity (S)

1. Negligible – Minimal or no impact

2. Significant – Leads to reduced experiment performance

3. Major – Leads to failure of subsystem or loss of flight data

4. Critical – Leads to experiment failure or creates minor health hazards

5. Catastrophic – Leads to termination of the project, damage to the vehicle or injury to personnel

Table 3-1: Example of risk index and magnitude scheme

Probability (P)	1	2	3	4	5
E	low	medium	high	very high	very high
D	low	low	medium	high	very high
C	very low	low	low	medium	high
B	very low	very low	low	low	medium
A	very low	very low	very low	very low	low
	Severity (S)				

Table 3.5-1 Risk Register

ID	Risk and consequence	P	S	P x S	Action
R1	Valves fail to open	C	3	Low	Execute tests to ensure that

(MS)	preventing samples' collection				valves work properly in flight conditions
R2 (MS)	Valves fail to close causing the risk of samples contamination	C	3	Low	Execute tests to ensure valves to work properly in flight conditions
R3 (MS)	GPS fails, leading to unexpected opening or closing of valves	B	3	Low	Ensure redundancy and introduce possibility of override by ground station
R4 (MS)	GPS fails to determine experiment's position	B	4	Low	Altitude determination using both GPS and barometric pressure sensor
R5 (MS)	Communication fails	C	4	Medium	Redundancy employing data logging. Autonomous mode in case of no GS-ACK
R6 (MS)	Landing in water soaks instruments and samples	A	4	Very Low	Valves posed both on mount and valley of the filters. Accept the idea of losing electronics. Transmit data with E-link system in order to save data.
R7 (EN)	Required level of cleanliness is not achieved	B	3	Low	Implement strict flight procedures. Put spare control filters for analysis
R8 (EN)	Static charges accumulate interfering with AIC reading	D	2	Low	Assure correct grounding. Select low charging materials.
R9 (EN)	Vibrations affect instruments' performance and SD	B	3	Low	Vibrational tests. Dumpers
R10 (EN)	Electromagnetic interference from other experiments	B	3	Low	Shielding of sensitive electronics, guarding circuits, correct grounding
R11 (TC)	Electronics' operational temperature range is exceeded	C	4	Medium	Detailed thermal simulation and testing. Include external heaters
R12 (TC)	OPC's operational temperature range is exceeded	C	3	Low	Detailed thermal simulation and testing. Include external heaters

R13 (TC)	AIC's operational temperature range is exceeded	C	3	Low	Detailed thermal simulation and testing. Include external heaters
R14 (TC)	Pump overheats	B	3	Low	Detailed thermal testing in vacuum chamber
R15 (TC)	Battery fails	B	4	Low	Ensure redundancy and choose priority so that the main mission gains priority
R16 (TC)	Battery explodes	A	5	Low	Control battery output tension in order to foresee discharge and avoid over-exploitation
R17 (TC)	Temperature sensors fail	B	3	Low	Choose homologate sensors and test them. Several sensors put in key positions
R18 (PE)	Personnel unavailable unexpectedly	B	4	Low	Ensure all sub-systems are covered. Recruit back up resources
R19 (PE)	Components not available steadily	A	4	Very Low	Order components in time
R20 (PE)	Critical component destroyed during testing	B	4	Medium	Order multiple pieces of low cost components and test critical components early. Detailed investigation in case of test failure and possible changes in design.
R21 (PE)	Not enough funds for the experiment	C	4	Medium	Outreach and early fund-raising
R22 (PE)	Not enough funds for travelling and accommodation	D	2	Low	Acceptable risk. Fundraising
R23 (PE)	Conflicts within the group	C	2	Low	Try mediation. Lot of effort in building team spirit
R24 (PE)	Overload of work for a team member	C	2	Low	Detailed WBS. Each system should be assigned to at least two team members
R25	Lack of expertise	C	2	Low	Use of BEXUS mentorship.

(PE)					Help from university professors and technicians
R26 (PE)	Schedule is not followed	C	3	Low	Use and update Gantt chart. Set milestones.
R27 (PE)	Delay during experiment shipping to Esrange	C	4	Medium	Arrange early shipping
R28 (TC)	Software program in micro-controller fails during flight	B	4	Low	Testing and introduction of GS override
R29 (VE)	Instruments are damaged at landing	C	3	Low	Test and simulate resistance of the mechanical structure. Dampers

4 EXPERIMENT DESCRIPTION

4.1 Experiment Setup

The experiment is composed of different sub-sections, each one with specific functions and features:

- **Instruments Housing Assembly (IHA)**. It contains all the main scientific instruments: the two AIC's, the OPC, the Pump, and the Sampling Unit (SU).
- **Electronic Control Unit (ECU)**: It is located into the EHA and it contains the Arduino Micro-controller, the stacked PCB's, pressure sensor, humidity sensor, power board, and thermal control board.
- **Battery Unit:** It is located inside the BHA and it hosts the two battery pack.

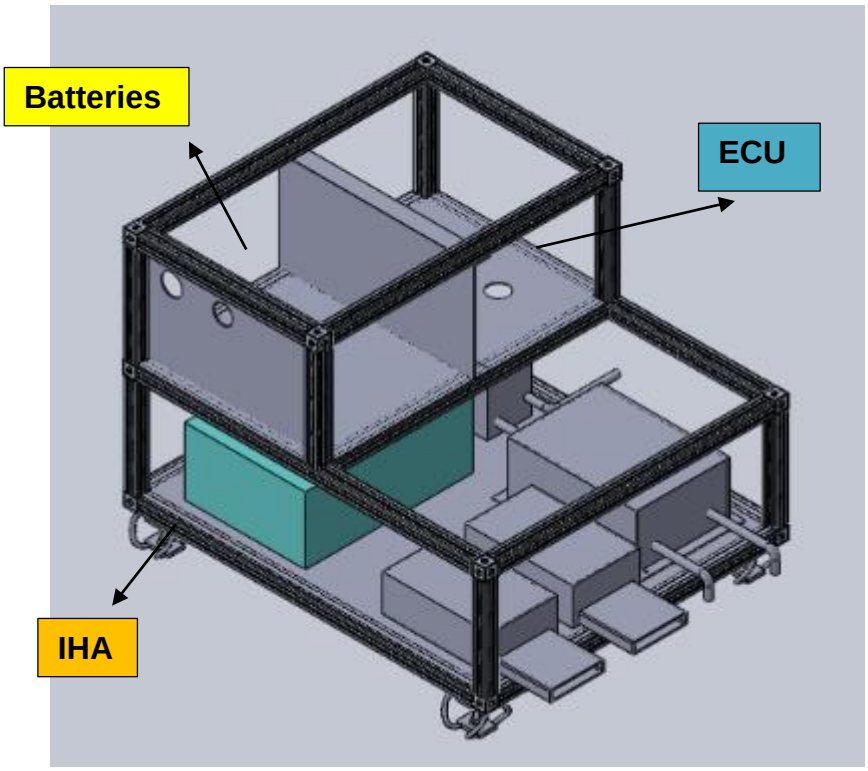


Figure 4.1-1 Experiment overview

The core of the experiment is represented by the instruments inside the IHA:

- **Optical Particle Counter (OPC):** this device uses a pump to create an airflow through the inlet tubing and draw air from outside the gondola. The air then passes through an optical system capable of determining

the size distribution of particles (n/cm^3 for each selected size interval), and finally exits from an exhaust pipe. The OPC will be kept on for the whole flight, allowing for the creation of a continuous vertical profile.

- **Air Ion Counters (AICs):** these devices use a fan to create an airflow and draw air from outside the gondola. Ions present in the air are diverted from the flow and collected on a plate which gives a voltage output proportional to the number of ions collected (n/cm^3). The air is then expelled downwards through the bottom plate. Also AICs will stay on for the whole flight, allowing the creation of a vertical profile.

- **Pump and Sampling Unit (SU):** Once reached a nominal altitude in the stratosphere, the pump is used to create an airflow through the Sioutas sampler in order to collect aerosol samples. Valves posed both before and after the SS are opened only during sampling phase, and remain closed for the rest of the flight to avoid contamination from non-stratospheric particles.

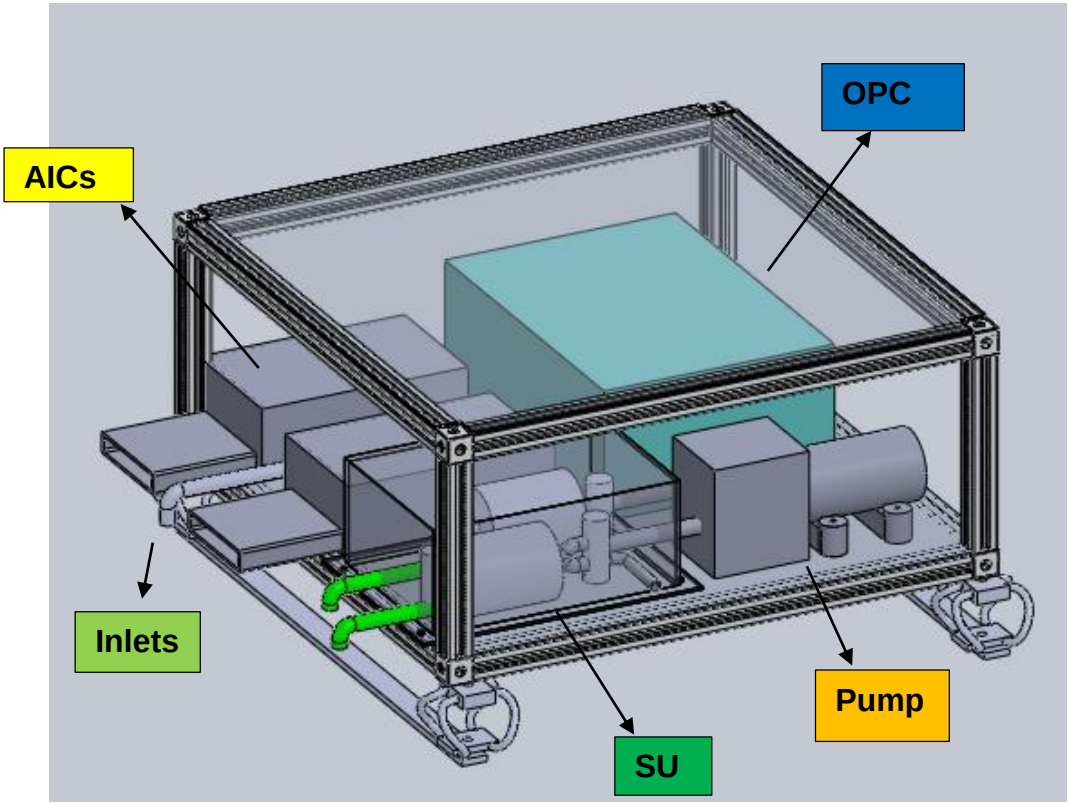


Figure 4.1-2 Main scientific instruments

4.2 Interfaces

4.2.1 Mechanical

The experiment housing has been designed to suit all mounting requirements specified in the BEXUS user manual. The spacing of the feet and the slot sizes have been incorporated in the mechanical design such that it fits on the M-EGON gondola.

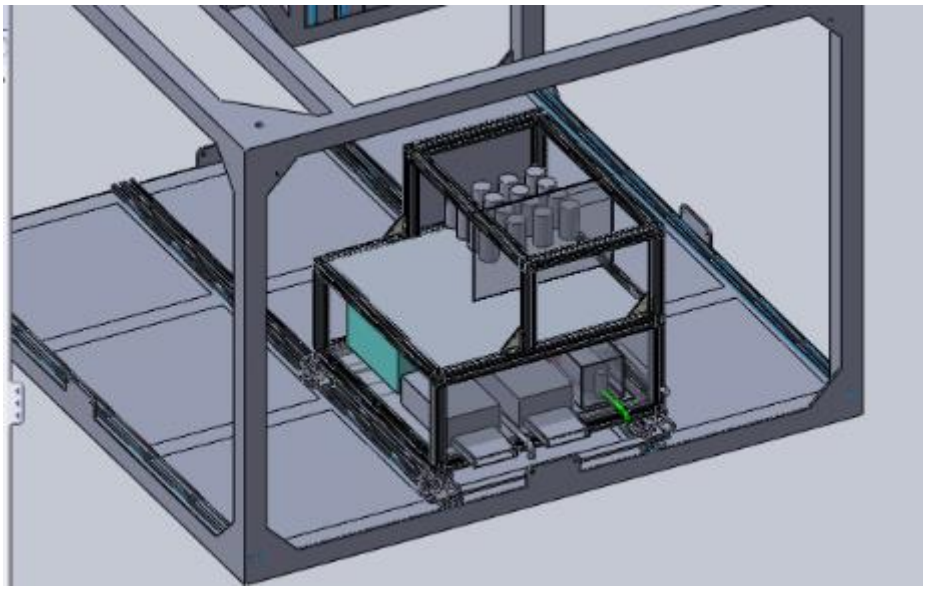


Figure 4.2-1 Experiment mounting in M-EGON gondola

- The experimental setup will be bolted to the gondola using the standard screws specified in the BEXUS user manual that will be fixed with Loctite glue once definitive mounting is performed.
- The experiment is mounted on four Enidine ® Compact wire rope springs (CR6-100) to reduce the forces experienced during landing. The CR6-100 spring has the highest load rating in the entire series and is capable of supporting a maximum static load of 133N. Also these mounting devices are very versatile due to the possibility of sliding along the aluminium extrusions and so allowing late adjustments in design (Fig. 4.2-2)
- No hole in the gondola floor is required, while the external fabric cover should be removed on one side to facilitate the external air suction by OPC and piping of the SU

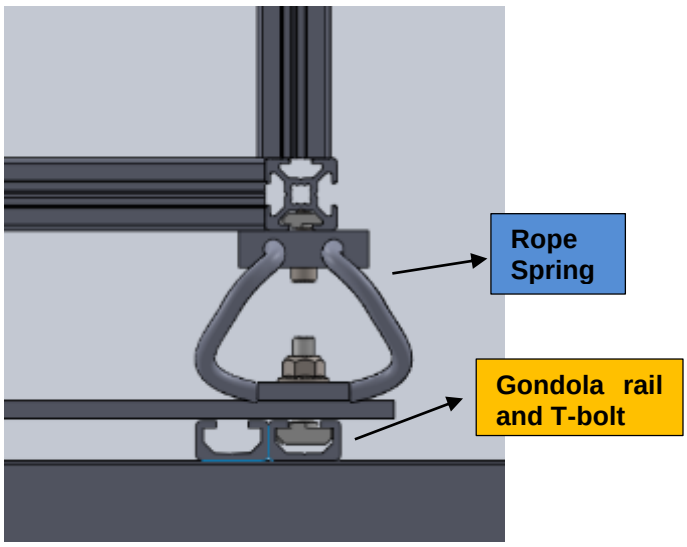


Figure 4.2-2 Mounting detail

4.2.2 Electrical

The electrical interface will enable the connection between the experiment and Ground via the E-link. As the experiment outputs data serially through the microcontroller, an RS232 to Ethernet module will be used to convert the serial signal to transmit it over the E-link. This signal will then be converted back to the serial protocol when it arrives to Ground.
The experiment's Ethernet cable will be mated to the E-link connector, an RJF21B, with an RJ45 Ethernet jack. During flight, the outside interface of the RJF21B will be connected to the E-Link unit using a cable provided by EuroLaunch. During testing, the Ground station will be directly connected with a normal RJ45 Ethernet jack.

Figure 4.2-4 RJF21B socket

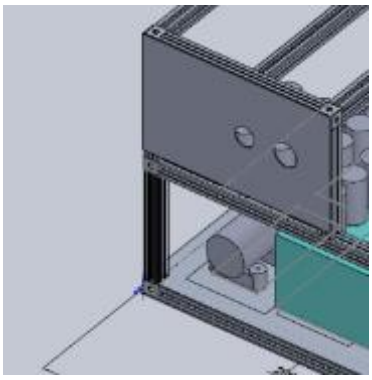


Figure 4.2-3 RJF21B mounting

4.3 Experiment components

Table 4.3-1 Experiment summary table

Experiment mass (in kg):	9 kg
Experiment dimensions (in m):	450mm*445mm*412mm
Experiment footprint area (in m^2):	0.20 m^2
Experiment volume (in m^3):	0.08 m^3
Experiment expected COG (centre of gravity) position:	300mm x axis 270mm y axis 210mm z axis

4.3.1 Optical Particle Counter (OPC)

Overview

Our initial choice for the particles' size measurements was to use the 212 profiler OPC from Met one Instruments, but after the vacuum chamber test (OPCT2) it was shown that this instrument gives a reliable output only for pressures down to 500 mbar and, since we already have it, it will be considered only as a backup solution in case of any trouble with the new model.

Our choice is now to use the LOAC instrument from Meteo-Modem, which is already involved in several research programs of atmospheric studies and has proved to work in high altitude balloons.

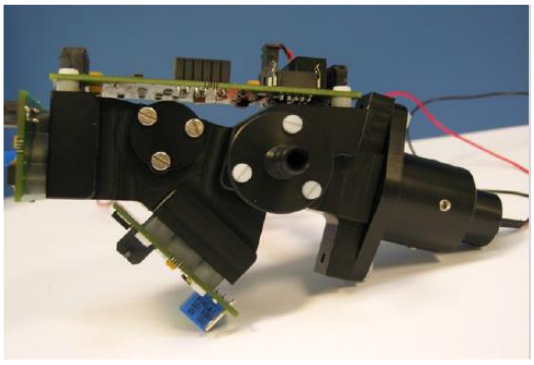


Figure 4.3-1 LOAC

This instrument is capable of measuring aerosols' distributions in 20 size classes between 0.3 and 50 µm and, thanks to measurements of light scattering at two different angles (one sensitive and one insensitive to particles' shape) is capable of accurately determining the size and estimating the main nature of aerosols. This feature is particularly interesting when combining this instrument to the collections of samples that could be used as a check for these estimations.

Table 4.3-2 LOAC specifications

LOAC (Meteo-Modem)	
Particles' size	0.3 to 50 µm (19 channel bins)
Measurement range	0 to 2000 particles/ cm^3

Integration time	10 s
Light source	Laser diode 25 mW @ 635 nm
Sampling flow rate	1,6 l/min (typical)
Operating Range	-20° to 25° C
Power	7,2 VDC 450 mA ± 30 mA
Weight	250 g
Size	250 x 180 x 100 mm
Communication	RS 232 or I2C

4.3.2 Diaphragm Pump

Pump 7500	**Boxer Pumps**
Performance	Flow rate up to 32 l/min
Type	Diaphragm pump, magnet brushed DC motor
Operating Range	-50 to +50 C
Power	12 V DC Max current 3 A
Weight	1.1 Kg
Size	168*86*83 mm

Figure 4.3-2 Boxer 7000 Pump

Our current design employs the use of a 7500 BOXER pump, capable of generating an airflow up to 32 l/min. This will be used to generate the flow inside the SU and in particular inside the SIOUTAS sampler. Since this device requires a specific flow rate of 9 l/min to correctly sort the particles by their size, an active control of the supplied voltage (and hence the flow) has to be performed. To achieve this we will employ a “Motion Mind DC Motor Controller” board. Detailed testing will be performed in vacuum chamber to determine the amount of voltage required to achieve the correct flow. (See PT1 and PT2)

4.3.3 Air Ion Counters (AICs)

We chose to use two AIC's from Alphalab Inc. for the ion density measurements. One will be used for positive ions and one for the negative ions.
These operate in the following way: oustide air is pulled inside the instrument by a fan at a rate of 24 l/min and, as it passes through the meter, negative (or positive) ions are taken from the flowing air and deposited onto an internal collector plate by a ±10V voltage difference between the plate and the external walls. The number of elementary charges per second that hit the collector is found by measuring the voltage of the collector plate, which is connected to ground through a 10 G ohm resistor.
In table 4.3-3 some of the key features of the AIC's are listed

Figure 4.3-3 AIC

Table 4.3-3 AIC specifications

Air Ion counter	AlphaLab
Range	0 to 200K ions/cm^3 (0 to ± 2 V output)
Offset	± 1 to 100 mV
Noise	10 ions/cc (2s averaging)
Operating Range	-50 to +50 C
Power	10 to 14 VDC Fan On 45 mA (typical) Fan Off 4 mA (typical)
Weight	305 g
Size	160 x 100 x 55 mm

As mentioned in section 3.5 there are some effects that can interfere with the ion readings and should be avoided:

- The presence of static charges near the AIC's should be avoided, since an excess of charges near the top slot would cause a lower reading since ions would be deflected away (same charge) or attracted towards the inlet instead of the collector plate (opposite charge). In order to avoid this effect, the AIC case, which is coated by a conductive material, has to be

connected to ground (with the supplied long cord). Moreover any plastic material used in the structure will be selected also considering its charging properties.

- The inside of the meter can become dusty. In that case the dust can create a slightly electrically-conducting bridge between the internal collector plate and the metal chamber which surrounds the collector plate, causing an increase in the offset value for output voltage.

In order to mitigate these effects some pre-flight checks have to be performed to verify the correct grounding and cleaning has to be done on a regular basis and especially before mounting the instruments in the gondola. (See chapter 6 for pre-flight procedures)

4.3.4 Sampling Unit (SU)

For the sample collection we chose to use a SIOUTAS Impactor. It is a device that efficiently samples ultrafine, fine and coarse (>2.5 µm) particles simultaneously.
When aerosol impinges on or flows around a surface the air is diverted by the surface; but if the particles are sufficiently large or dense the inertia can cause them to impact on the surface, where they may then be retained.
The SIOUTAS sampler is optimized for a flow rate of 9 l/min, perfectly achievable with the BOXER pump through an active control of the magnet brushed motor.

Figure 4.3-4 Sioutas Impactor

Choice of device

To get a meaningful detection, the mass of the caught particles needs to make up at least 1 ppb of the mass of the filter.
The relative mass of the caught particles can be estimated as follows:

$$C = \alpha \frac{M_p}{M_f} = \alpha \frac{N m_p}{M_f} = \alpha \frac{n V m_p}{M_f} = \alpha \frac{n \phi t m_p}{m_f} \quad (1)$$

Where:
C is the relative mass of the caught particles
α is the sticking ratio
M $_p$ is the total mass of the caught particles [kg]
M $_f$ the mass of the filter [kg]
N the total number of particles
m $_p$ the average mass of the particles [kg]
n the particle density [m^{-3}]

V the total volume of air sucked [m^3]
φ the air flux [$m^3\ h^{-1}$]
t the total sampling time [h]

One can estimate values for the different quantities in equation (1) and therefore make a first rough estimation of the relative mass of the particles: taking α = 0.5, $n = 10^5\ m^{-3}$, φ = 0.54 $m^3\ h^{-1}$, t = 3 h, m_p = 1 µg, and m_f = 100g, one gets a relative concentration of:

$$C = 0.5 * 10^5\ [m^{-3}] * 0.54 \left[\frac{m^3}{h}\right] * 3\ [h] * \frac{1}{100}\left[\frac{\mu g}{g}\right] = 8.1 * 10^{-4}$$

All these values are very rough estimates, but the obtained relative value is five orders of magnitude larger than the needed value of C = 1 ppb = $1*10^{-9}$. With a floating phase of only 1 hour, we would have C = $2.7 * 10^{-4}$, that is still a suitable value for particle detection. However, if possible, a 3-4 hours floating phase would ensure a higher probability of collecting stratospheric particles with our assembly. This estimation does not take into account the contamination, which must be avoided.

Filter Choice

SKC (producer) recommends to use four 25-mm, 0.5-µm thick PTFE (Polytetrafluoroethylene**)** filters with laminated PTFE support as filters for the stages, and 37-mm, 2.0-µm PTFE filter with PMP support ring as after-filter.
We are currently following this choice due to the following considerations:

- Teflon filters result in high collection efficiency of particles above the cut-point of each stage without the use of adhesive coatings and do not collect excessively particles below the cut-point
- They can efficiently be used for gravimetric analysis [17]
- The fibre remains flexible and non-brittle from -73°C to +260°C without degradation.
- They have zero moisture absorption

Sampling Unit design

Driven by the design and operational requirements, and following previous experiments for the collection of stratospheric particles, such as DUSTER [7] and Stratospheric Census [8] the following design has been chosen in order to minimize the contamination of the samples:

- The SU will be sealed by Pinch Valves when in non-sampling mode, so prior to reaching the floating phase;
- Two pinch valves are mounted both upstream and downstream of the

SS to ensure insulation during non-sampling mode. The contamination from the balloon can be estimated to be maximum during launch and descent phase so valves have to be closed during these phases and will stay open only during the floating phase.

- Upstream valve has to be mounted as close to the inlet port as possible, in this way the number of particles that stick to a surface between the valve and the ambient atmosphere is minimized.
- The optimal direction to prevent contamination, especially from the balloon, is straight down, so the inlet pipe will point downwards.
- A blank filter, identical to the collection substrate, but not exposed directly to the airflow, is used to monitor the contamination inside the SU and in particular the one occurring during assembly and flight sequence.
- All mechanical parts with surfaces exposed to the sampling air are assembled in a class 100 clean-room, where they will be cleaned with ultrasonic cleaner before being assembled. Assembling and cleaning procedures for the SU are explained in more detail in chapter 6.

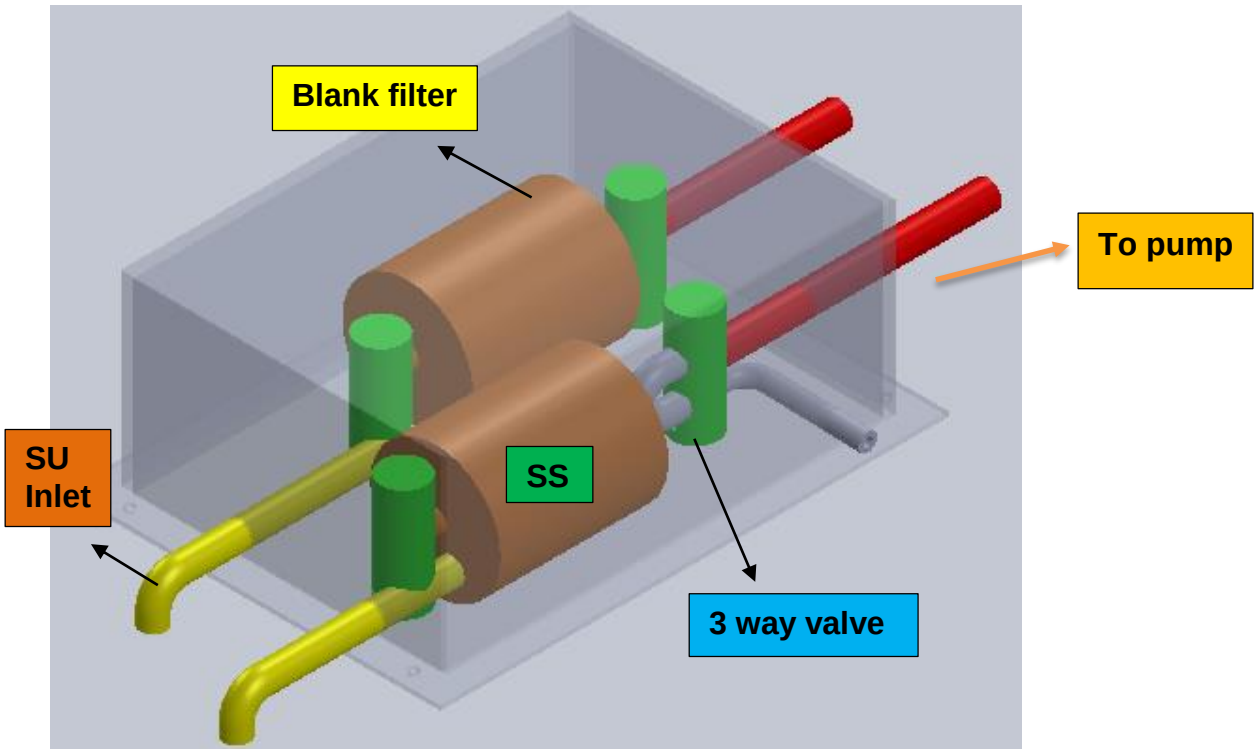


Figure 4.3-5 SU overview

4.4 Mechanical Design

Table 4.4-1 Mechanical Components

Components	Product number	Quantities
Cubic connector 20/3 Bosh	3842524478	16
20/40 Angular Bosh	3 842 538 517	12
20x 20 Beam Bosh	3842993231	28
CR6-100 wire rope Endine		4

The mechanical structure of the experiment is subdivided into three different sections: Electronics Housing Assembly (EHA), Instruments Housing Assembly (IHA), and Battery Housing Assembly (BHA). This choice has been taken in order to realize a modular structure that could be modified as easily as possible and assembled easily and quickly.

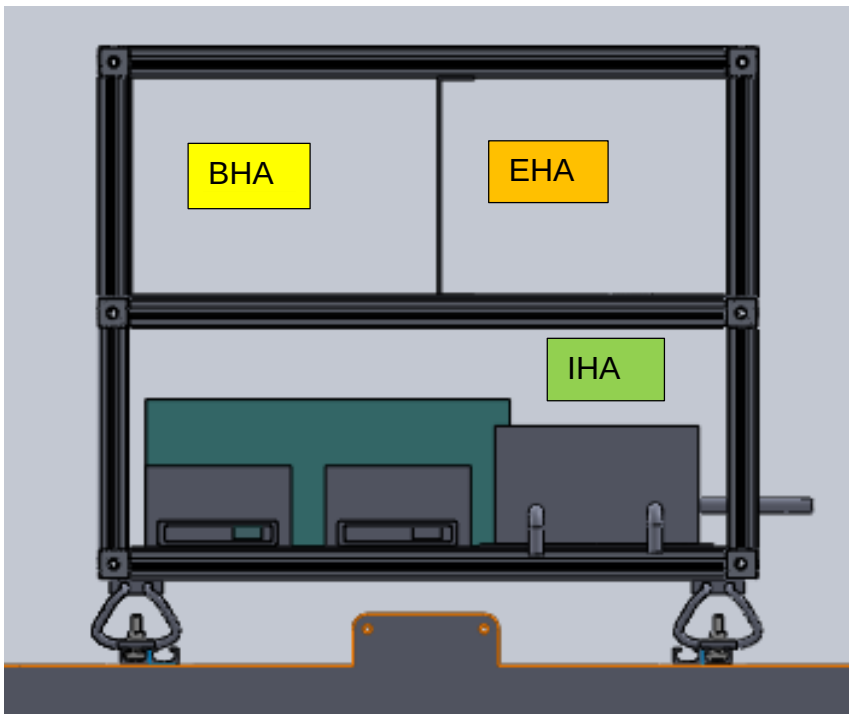


Figure 4.4-1 Experiment front view

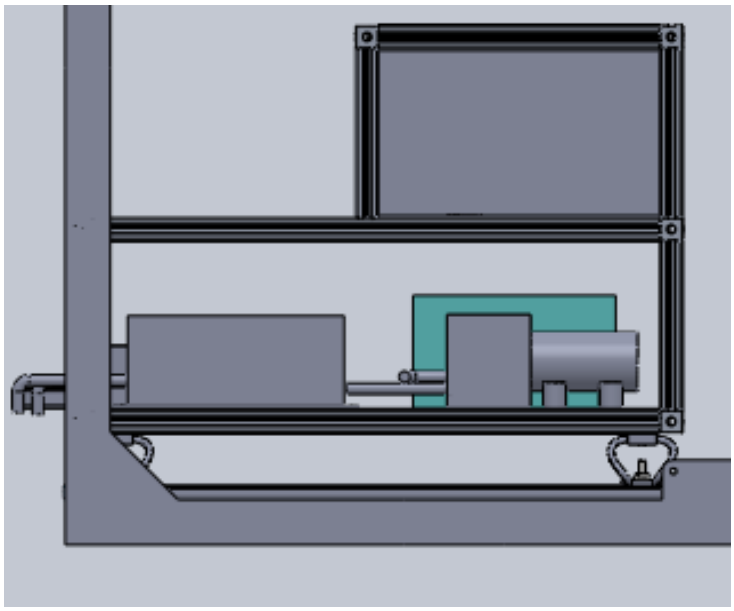


Figure 4.4-2 Experiment (side view)

The experiment is housed in a frame structure built up of Rexroth ® 20mm x 20mm grade 6061 aluminium extrusions as shown in Fig 4.4-2. The choice of this frame has been made due to its flexibility for future changes. To connect these frames, aluminium Cubic connectors (model 20/3 by Bosh) are being used.

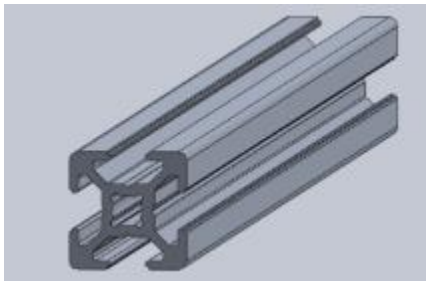


Figure 4.4-3 Aluminium Extrusion

4.4.1 Instruments Housing assembly (IHA)

The instruments housing is still made by Rexroth aluminium 20x20 profiles covered by aluminium sheet and an insulating layer as shown in Figure 4.4-5. It contains all the main scientific instruments: the two AICs, the OPC, the Pump, and the SU with its valves and Sioutas sampler.
The AICs, OPC, and SU must have access to the external air in order to gather valuable data, therefore they must be placed near the surface wall, where holes are created to host the inlets that guarantee the airflow.
Since the airflow for the OPC is quite low (up to a maximum of 3 l/m at ground level) no exhaust pipe is needed and the incoming air will be directly injected

inside the IHA where only a small venting hole will be inserted for pressure regulation.
On the contrary, Pump and AIC's will generate significant airflows (around 9 l/min and 24 l/min respectively), so in order to avoid internal pressure rise (due to small diameter of venting holes) and forced convective effects that can affect thermal regulation, exhaust pipes will be needed for all these instruments.

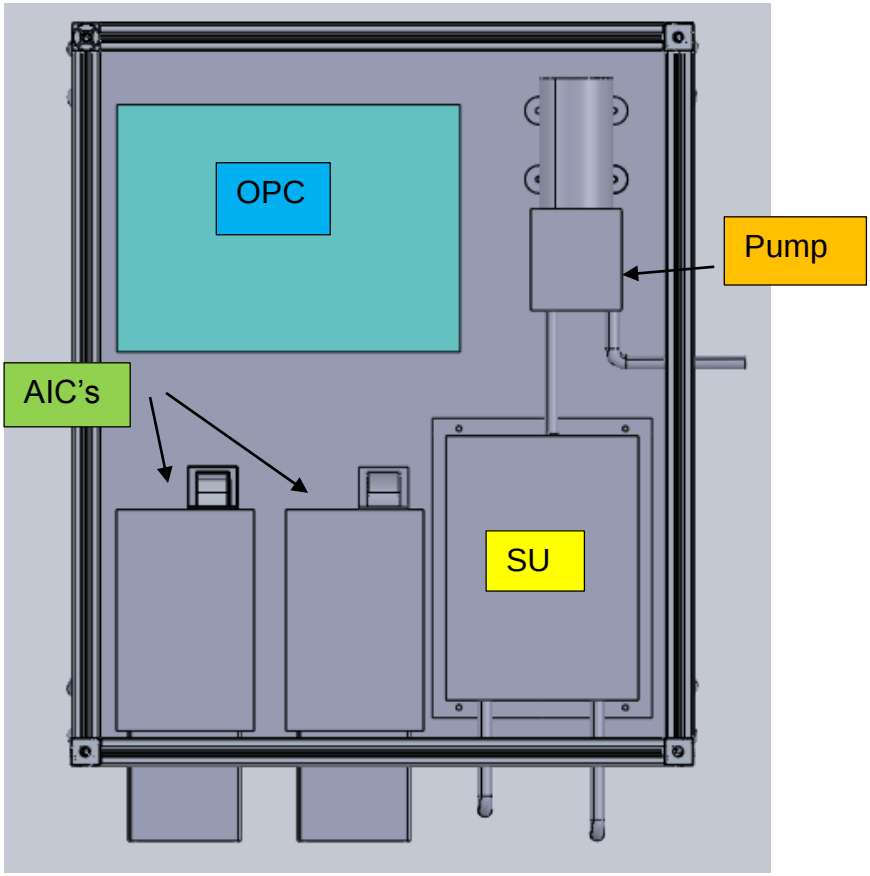


Figure 4.4-4 Instruments Housing Assembly (top view)

A series of particular design are being implemented for safety reasons:

- The pump will be mounted on the bottom plate using a rubber thickness to reduce vibrations. The experiment is mounted on four Enidine®

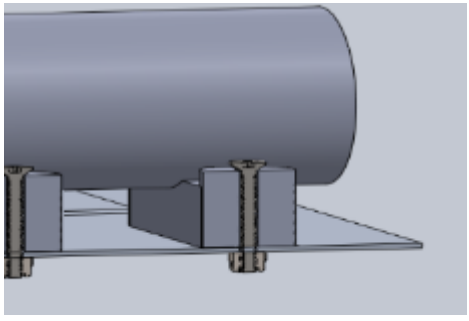


Figure 4.4-5 Rubber thickness detail

Compact wire rope springs (CR6-100) that will also help in reducing vibrations generated by the pump and the external environment.

- Since the optics of OPC require fine alignment and are very sensible, a dedicated mounting provision will protect this instrument both by random vibrations and shocks (especially during landing).

- Since the aerosols' sampling requires a deep level of cleanliness and insulation, the SU will be mounted inside a separate box, fixed to the bottom of the IHA through four corner bolts. In this way the SU mounting will be performed inside a clean room, and only once this is done and SU is completely insulated it will be mounted inside the IHA. Also, during post-flight, this design will facilitate the removal of the SU and its safe transport to the clean room where the filters will be taken out. A preliminary sketch of the SU can be seen in chapter 4.3.4

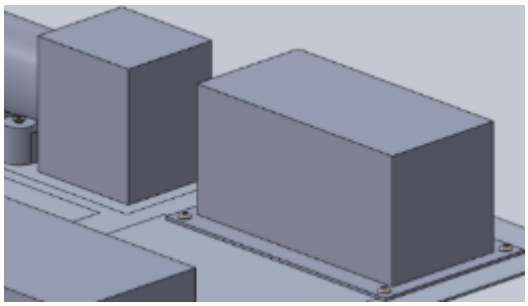


Figure 4.4-6 SU mounting detail

- The two AIC will be bolted directly to the bottom plate of the IHA, taking advantage of the simplicity of their structure. Two holes will be cut in the front aluminium panel to host the inlet slots of the two AICs. To facilitate the expulsion of drawn air, two metal slits are inserted at the exhaust hole.

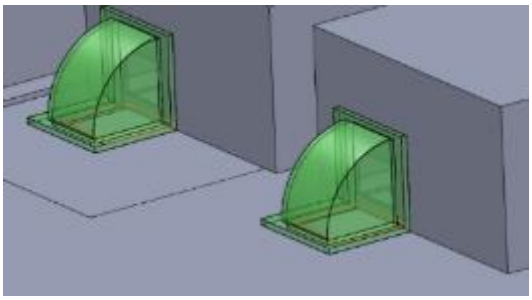


Figure 4.4-7 AIC exhaust slit

4.4.2 Battery Housing Assembly

The battery housing is made by Rexroth aluminium 20x20 profiles covered by aluminium sheet and an insulating layer as shown in figure 4.4-10.
The BHA shares the same support frame with the EHA, but the two are separated by a sliding aluminium plate that. A vertical plate installed on one side to facilitate the mounting of the power line and e-link connectors.

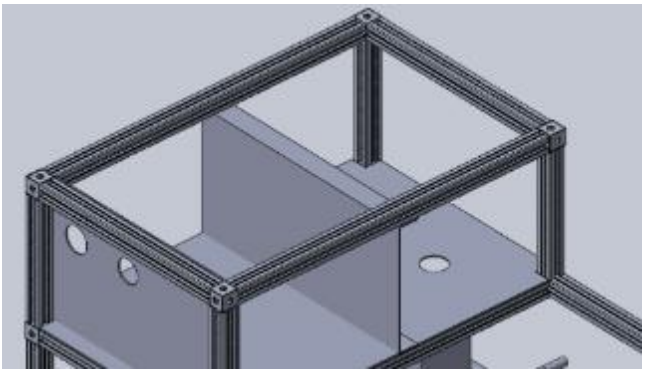


Figure 4.4-8 Battery and Electronic housing assemblies

4.4.3 Electronics housing assembly (EHA)

It contains the Arduino micro-controller with its stacked boards, the PCU board, the Heater's board and the Motion Mind motor controller.
As already stated it shares the support frame with the BHA from which it is divided by a sliding aluminium plate.
A central hole connects the EHA with the IHA and allows for the passage of cables and connections.

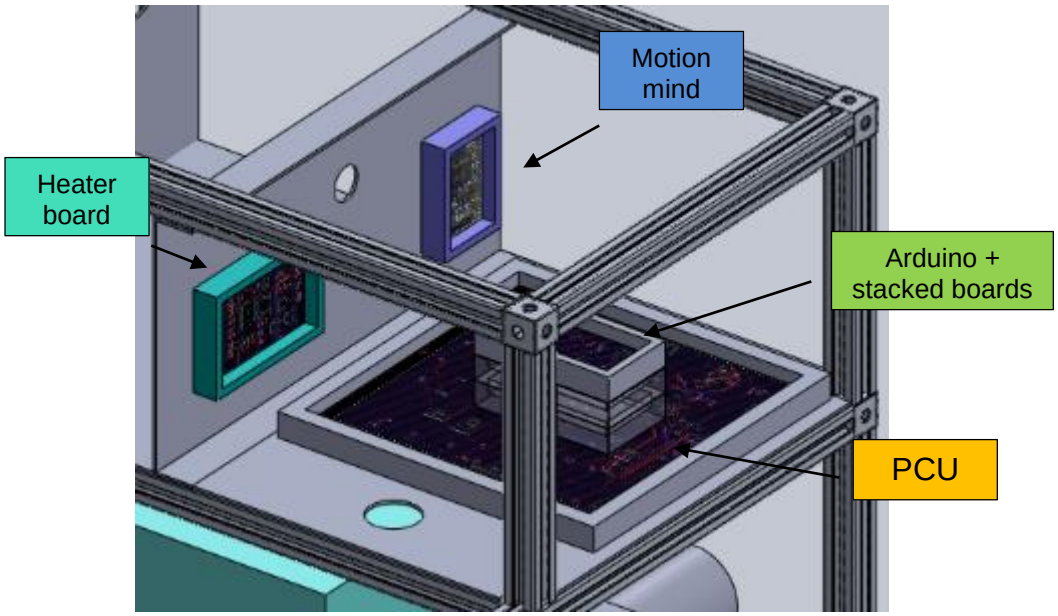


Figure 4.4-9 EHA detail

4.4.4 Structural analysis (10 g vertical)

A static structural analysis was performed for the A5 assembly considering a downward [negative Z axis] acceleration force of 10g. Components such as the filter holders, pumps, batteries and electronics were simulated as point masses coupled to their respective mounting plates. The plates, which are mounted on the Enidine® wire rope springs, have instead been considered directly linked to the frame and hence constrained in all degrees of freedom. The Enidine® wire rope springs were not simulated considering a conservative approach. The model was meshed in SolidWorks Simulation®.

Input data

- Material: 6061-T6 Aluminium alloy
- Young's modulus: 71 GPa
- Density: 2.77 x 10-6 Kg/mm^3
- Poisson's ratio: 0.33
- Yield stress: 276 MPa

The following table summarizes the performed analyses and the safety factors identified for the structure.

Table 4.4-2 Structural analysis' summary

Axis	G	Von Mises stress (MPa)	Yield stress (MPa)	Max displacement mm	Safety factor
Z	10	57.86	275	1.93	4.77
X	5	37.55	275	0.1713	7.32
Y	5	30.44	275	0.2234	9.03

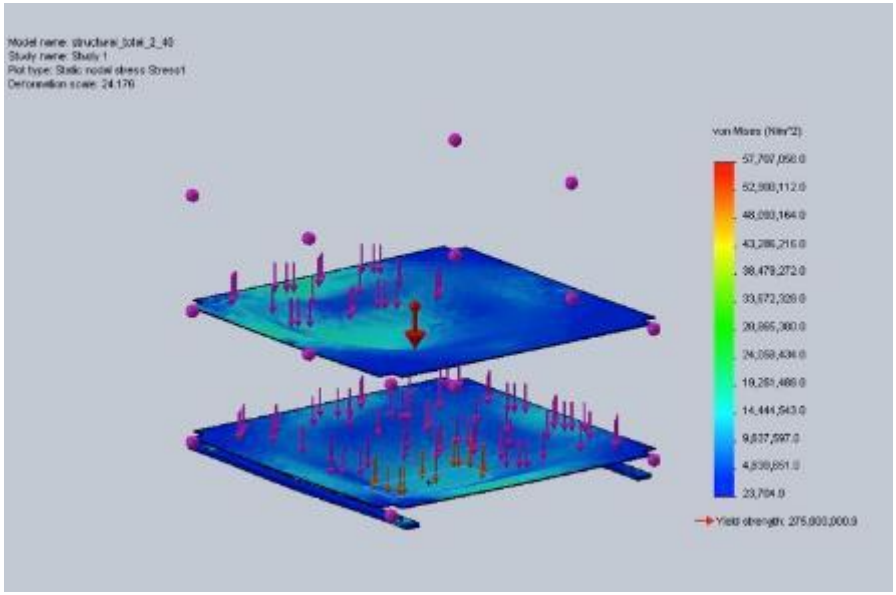


Figure 4.4-10 Von Mises 10 g vertical

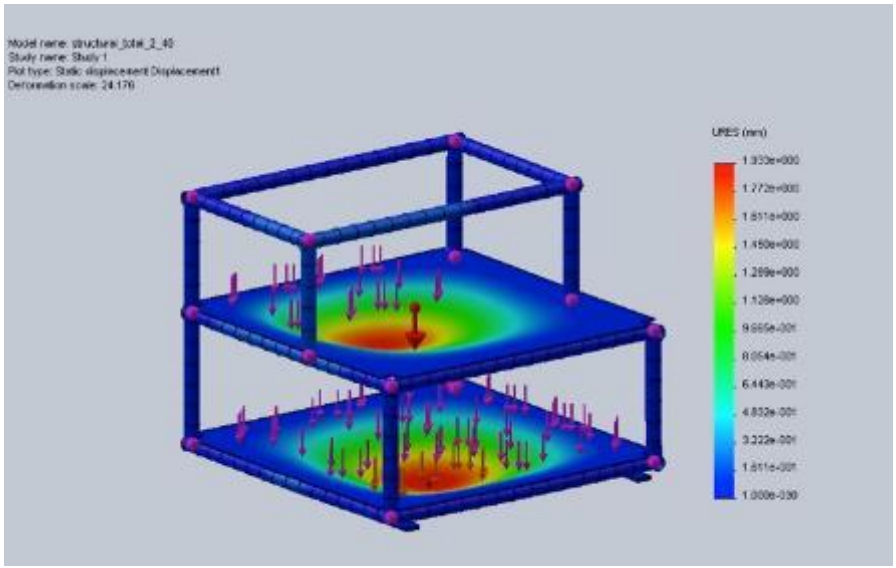


Figure 4.4-11 Z axis displacement

4.4.5 Structural analysis (5g horizontal)

The structure was analysed separately for two types of loads. An acceleration load of 5g in the horizontal X-axis and horizontal Y-axis direction. The boundary conditions were the same as the ones considered in the previous section for the -10g vertical analysis, except for the direction and magnitude of the load.

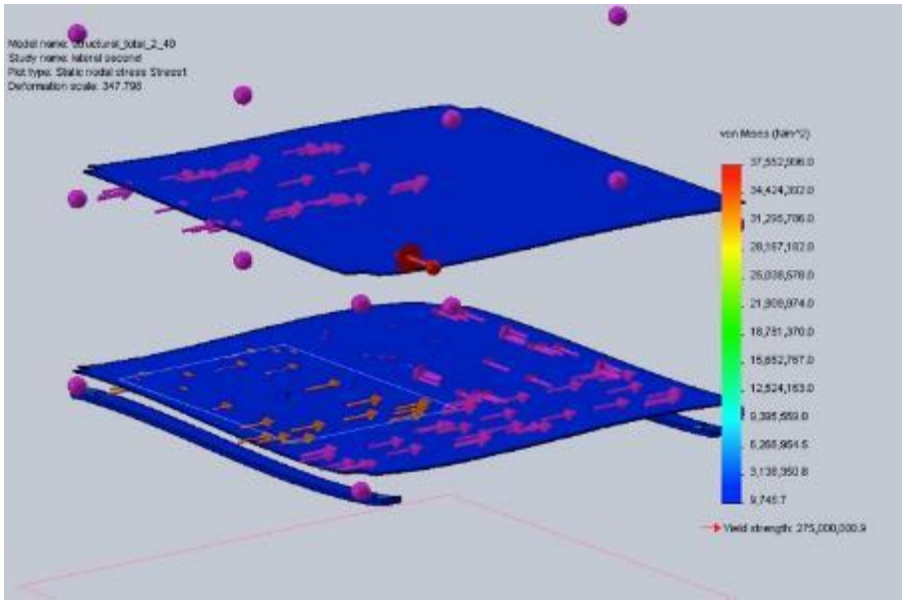


Figure 4.4-12 Von Mises 5 g (x axis)

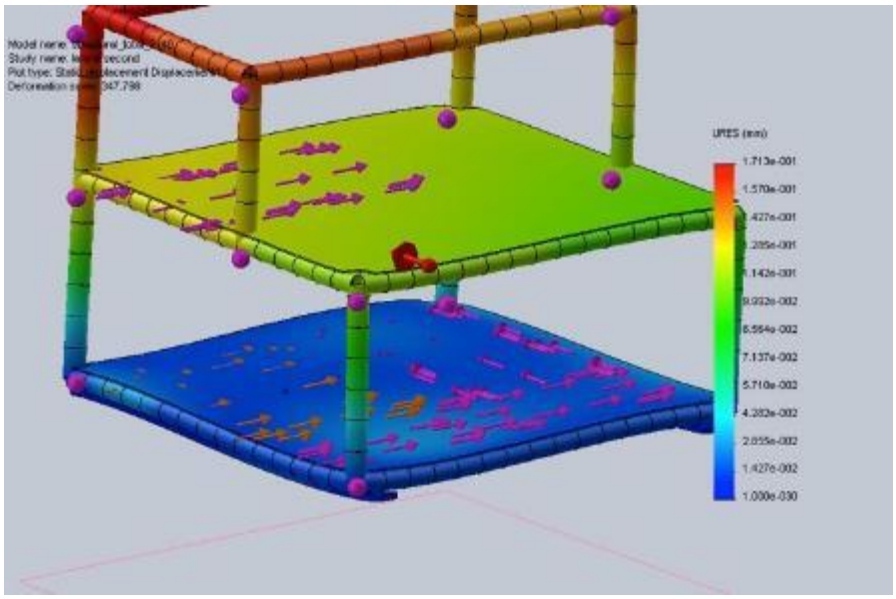


Figure 4.4-13 X axis displacement

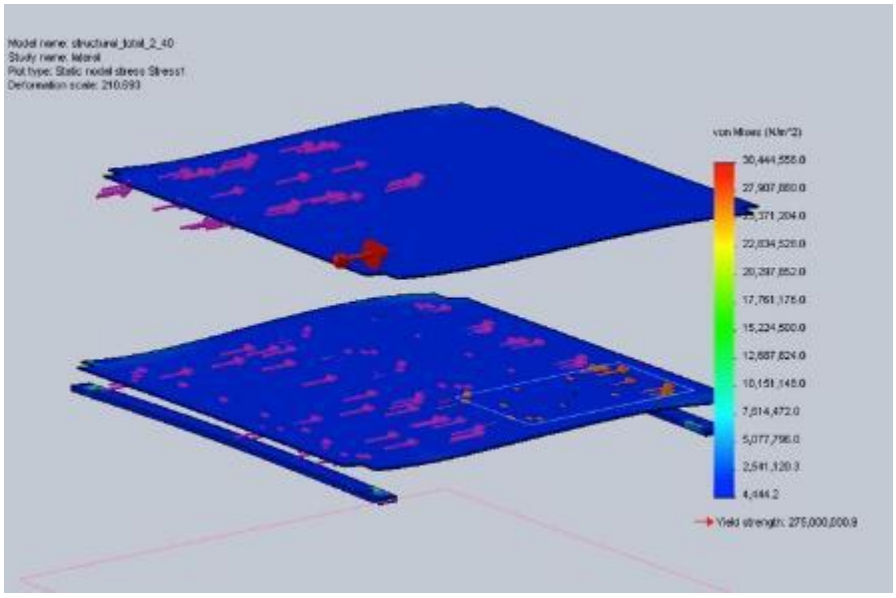


Figure 4.4-14 Von Mises 5g (y axis)

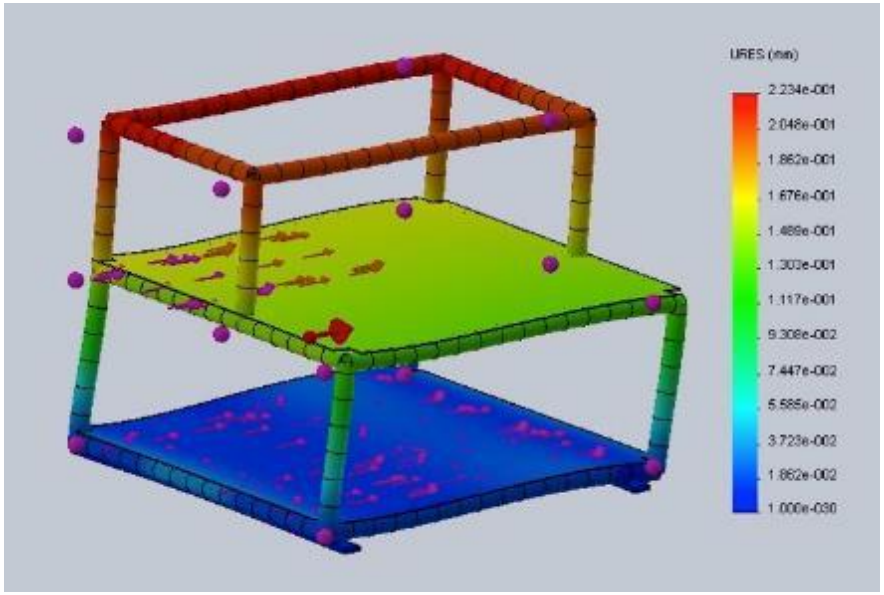


Figure 4.4-15 Y axis displacement

4.5 Electronics Design

A5-Unibo will use an Arduino MEGA 2560 microcontroller for data acquisition from sensors and instruments and to control the electro-valves that will open the flow stream needed for taking the aerosol samples. Fig 4.5-1 shows the Arduino MEGA 2560 microcontroller.

4.5.1 Devices connected to Micro-controller

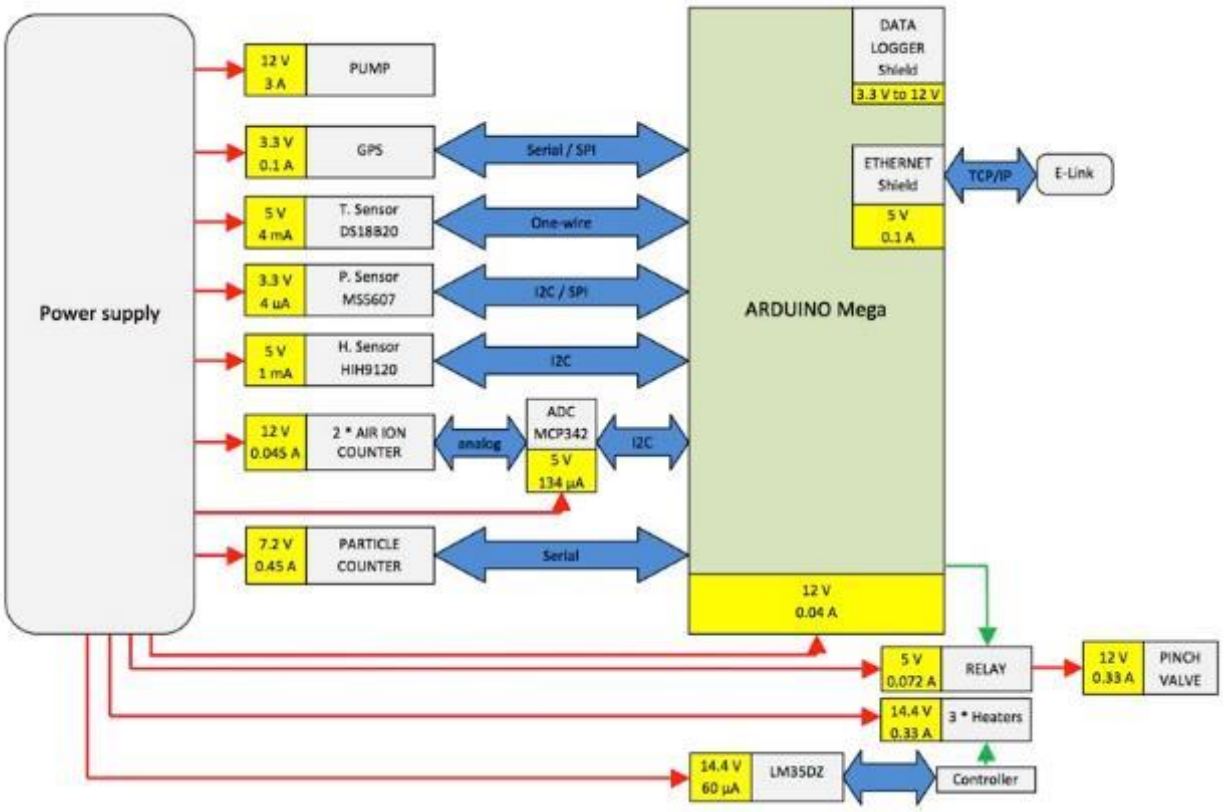


Figure 4.5-1 Devices connected to Arduino

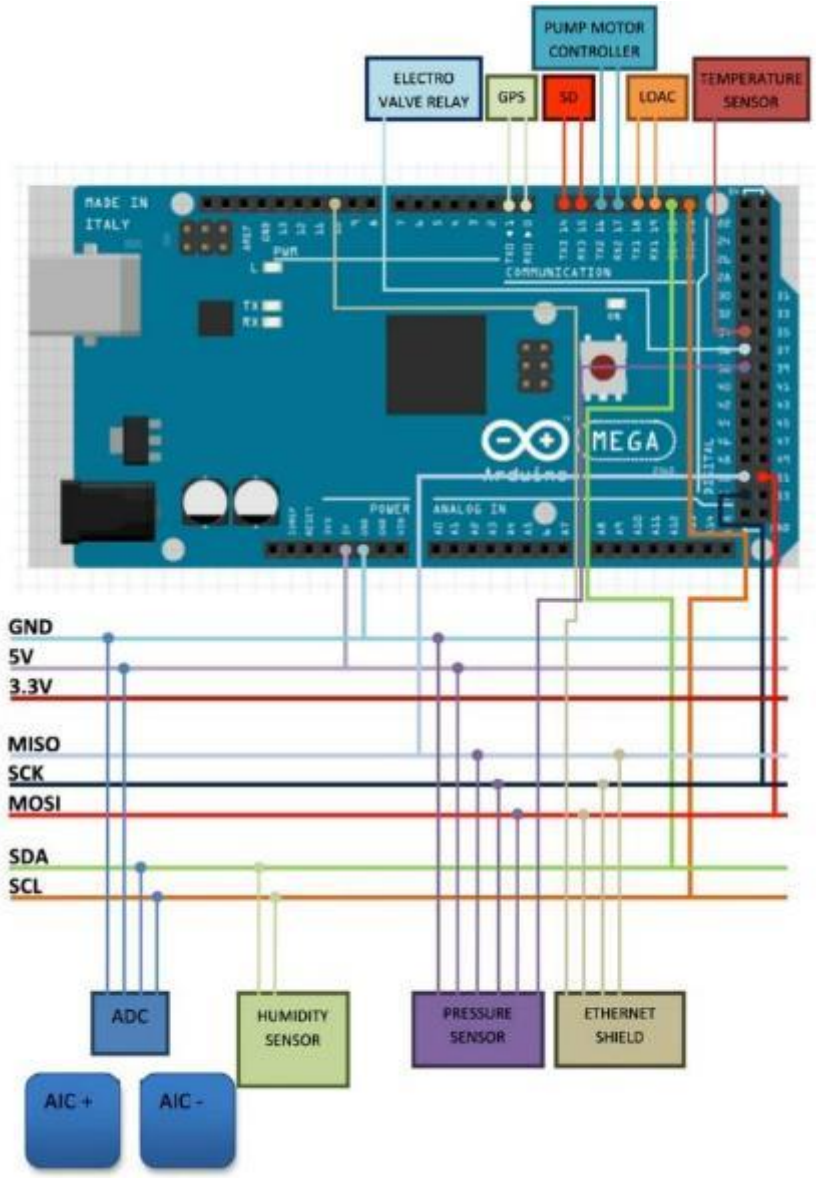


Figure 4.5-2 Arduino Mega and Pinning scheme

Fig 4.5-1 shows a diagram of the whole electronics interfaces with the power supply (red lines), the communications between the different sensors and instruments with the microcontroller (blue arrows), and switches for heater boards and relays (green lines).

The sensors and instruments used to achieve the goals of the experiment, use different ways to send data at the microcontroller.

The communication protocols (see APPENDIX F) that Arduino Mega 2560 uses are:

- SPI
- I²C

- ONE WIRE
- UART

Table 4.5-1 Sensors communications protocol

Sensors	Protocol
Pressure Sensor	SPI
AIC I(+)(analogic)-->ADC	I²C
AIC I(-)(analogic)-->ADC	I²C
Humidity Sensor	I²C
Temperature Sensor	One Wire
LOAC	UART

Table 4.5-2 Other devices communications protocol

Other Devices	Protocol	Pin
Electro-valves-->Relay	Digital Pin	36
SD	UART 3	TX3/RX3
Pump motor controller Motion Mind	UART 2	TX2/RX2
GPS	UART 0	TX0/RX0
Ethernet Shield	SPI	MOSI/MISO/SS

All of the sensors and instruments give a digital output except for the two AIC's whose analogic output needs to be converted into digital thanks to a 18-Bit, Multi-Channel ΔΣ Analogic-to-Digital Converter with I2C Interface and On-Board Reference (see fig 4.5-1 and 4.5-2)

A5-Unibo team has decided to design different printed circuit boards (PCB) in order to simplify and make more reliable the physical interfaces and connections between the different components.

The entire electronics interfaces with sensors and instruments will be designed in order to exactly fit with Arduino MEGA 2560 Board. The PCU (Power Control Unit) instead does not have very strict geometry requirements.

All of them are placed together in the electronics box as shown in the mechanical design.

4.5.2 Stacked board 1

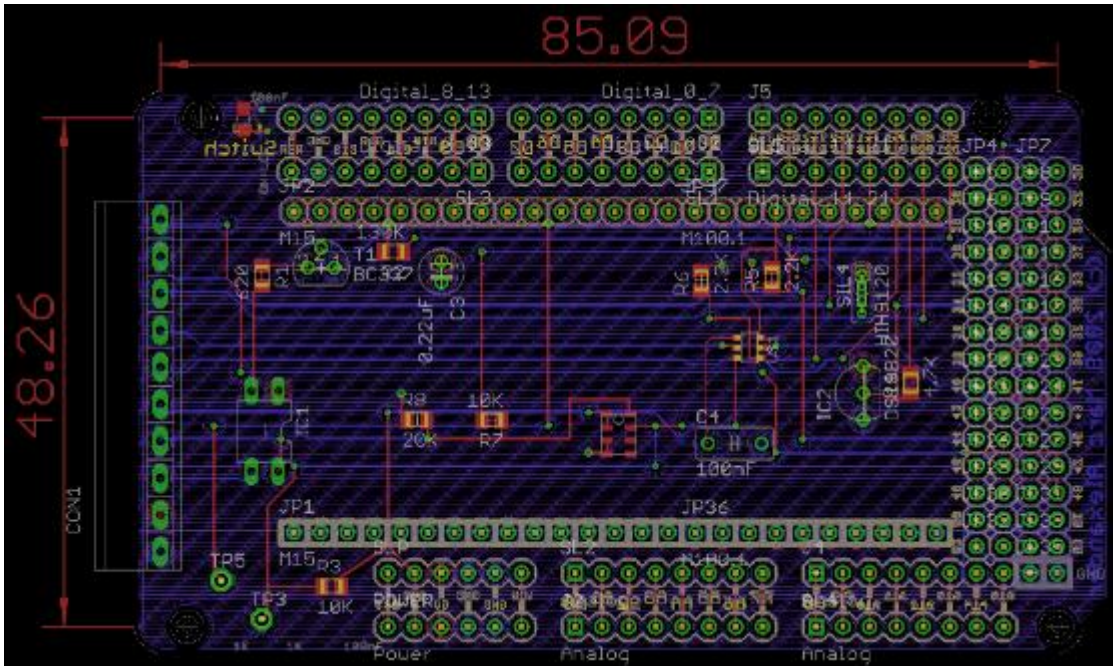


Figure 4.5-3 Stacked Board 1 (SB1)

Fig. 4.5-3 shows the stacked board SB1, the sensors and instruments connected are shown in table 4.5-3. Regarding the geometry, the board exactly fits with Arduino MEGA 2560 pin schematics, in order to overlap the microcontroller and optimize the space and volume used for the electronics subsystem and to avoid possible flying cables and failures due to bad contacts.

Table 4.5-3 SB1 Sensors and Instruments connected.

Component	Voltage	Comm.	Information	Fig.
Humidity sensor "HIH9120"	5V	I^2C	SCL, SDA, are pulled up with 2.2KOhm resistor.	4.5-6
Pressure sensor "MS5607"	3.3V	SPI	Connected to Arduino 3.3 V power line. In order to change the voltage levels, from 3.3 to 5V, a voltage divider TXB0101 has been included for sensor input pins and a level translator IC for the output.	4.5-7
Temperature sensor	5V	One wire	Pulled up with 4.7KOhm resistor.	4.5-8
Optical particle counter "OPC"	7,2V	UART	7,2V powered directly from CPU	.

LOAC			Converting RX and TX for UART using a RS232 to TTL converter.	
GPS	3,3V	UART	8 pin connector	-
Motor Controller (for PUMP)	14,4V	UART	8 pin connector	-

The PCB has four layers in order to reduce the space needed by the circuit and to have facilitate the separation of the different grounds. To make the system more reliable in terms of failure detection, some test points have been included in the PCB. In the following figures the general circuit schematics are shown.

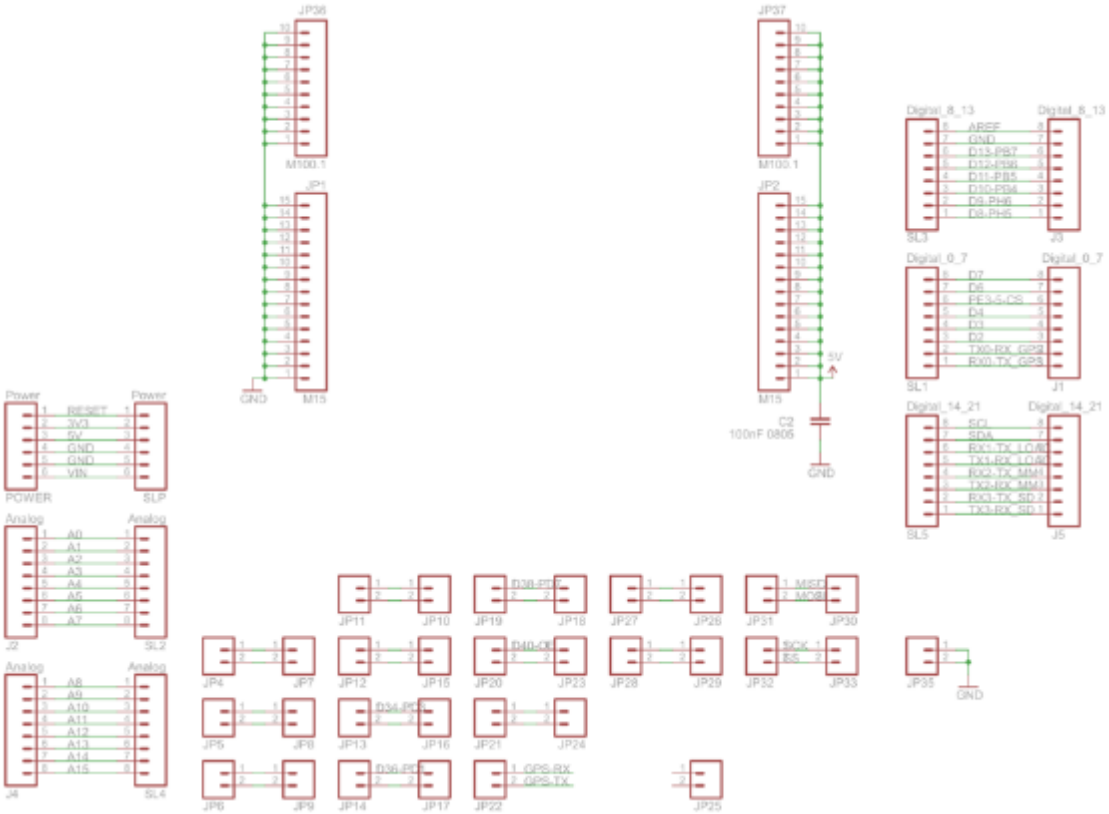


Figure 4.5-4 Stacked board SB1 schematics part 1

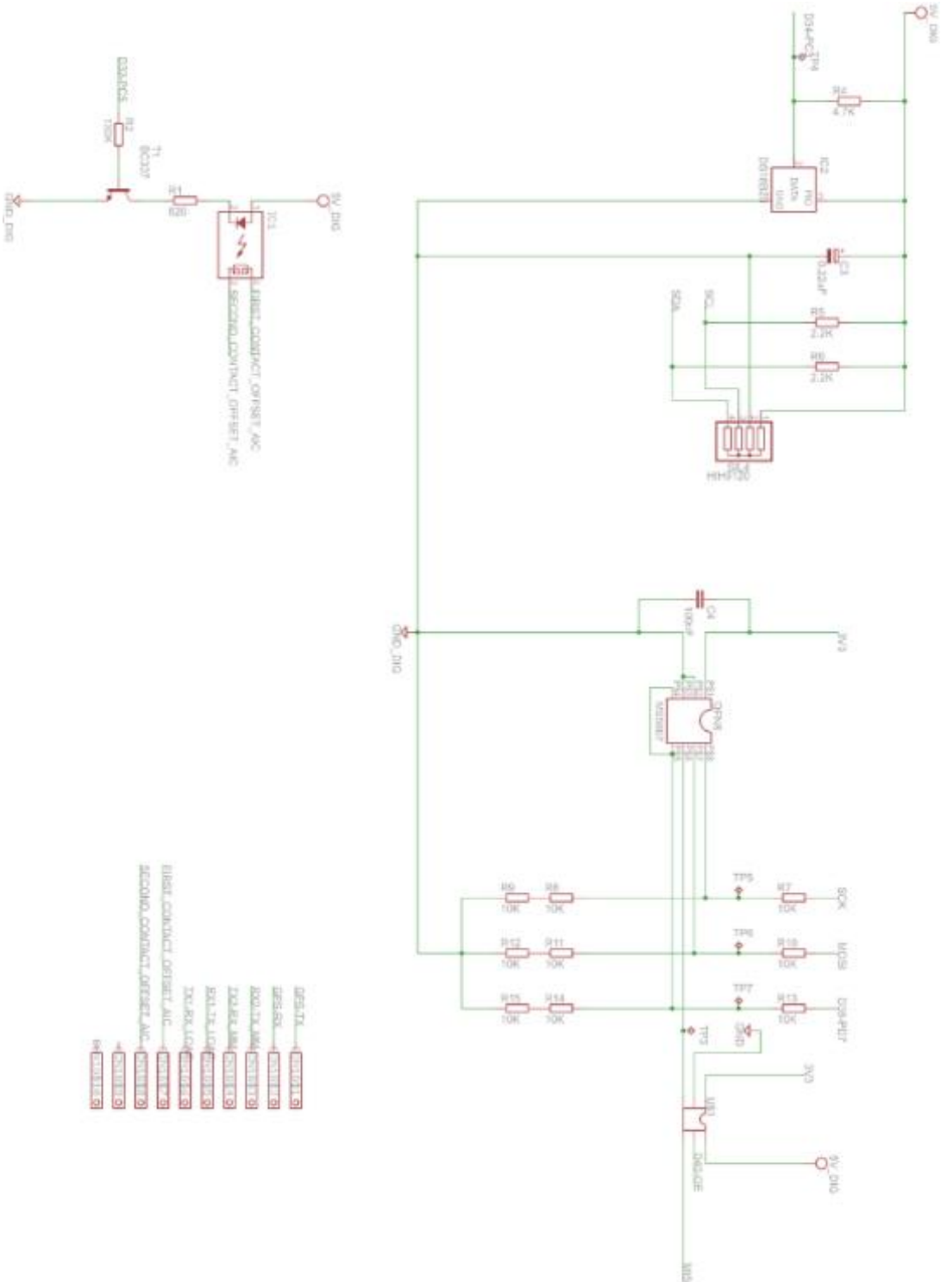


Figure 4.5-5 SB1 part 2 schematics

Fig 4.5-5 is fragmented into different parts depending on the function.

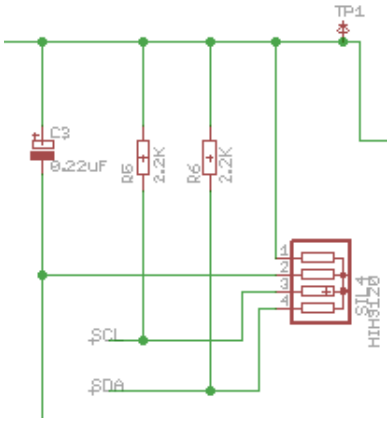


Figure 4.5-6 Humidity sensor schematics

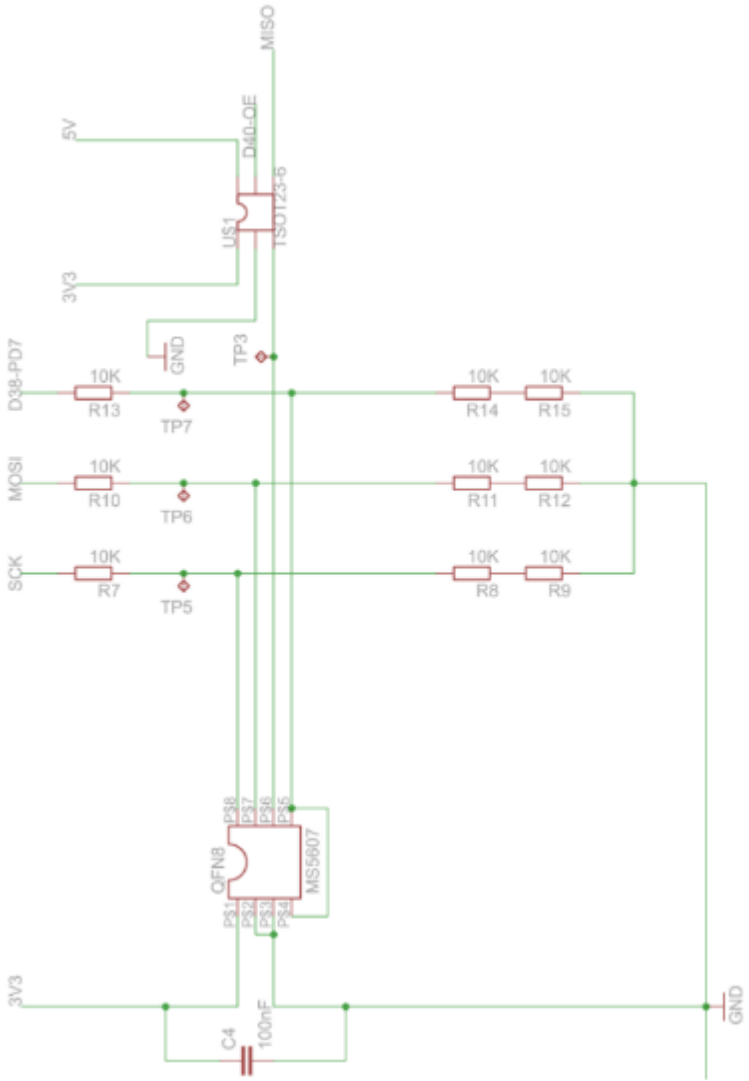


Figure 4.5-7 Pressure sensor schematics

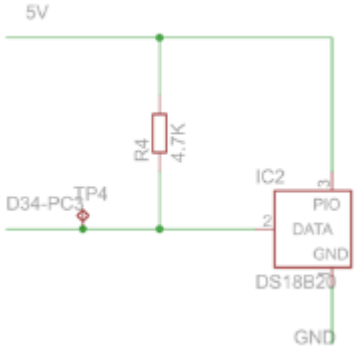


Figure 4.5-8 Temperature sensor schematics

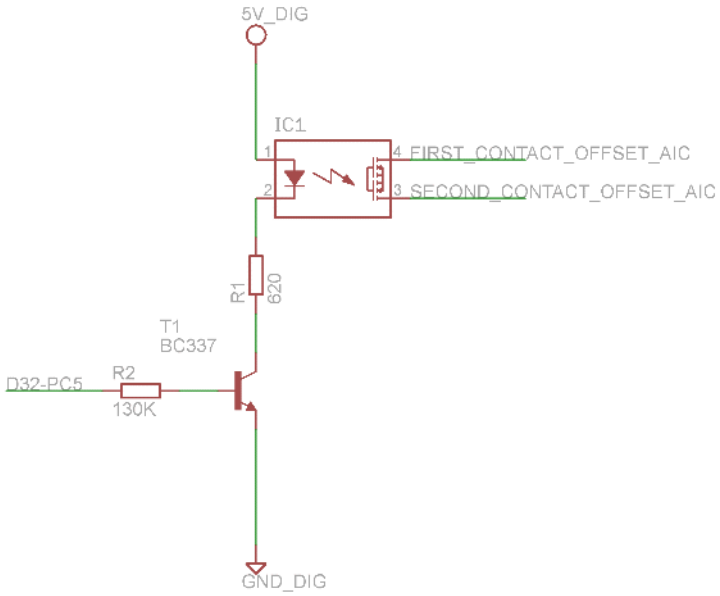


Figure 4.5-9 AIC offset closer

4.5.3 Stacked Sensor Board 2 (SB2)

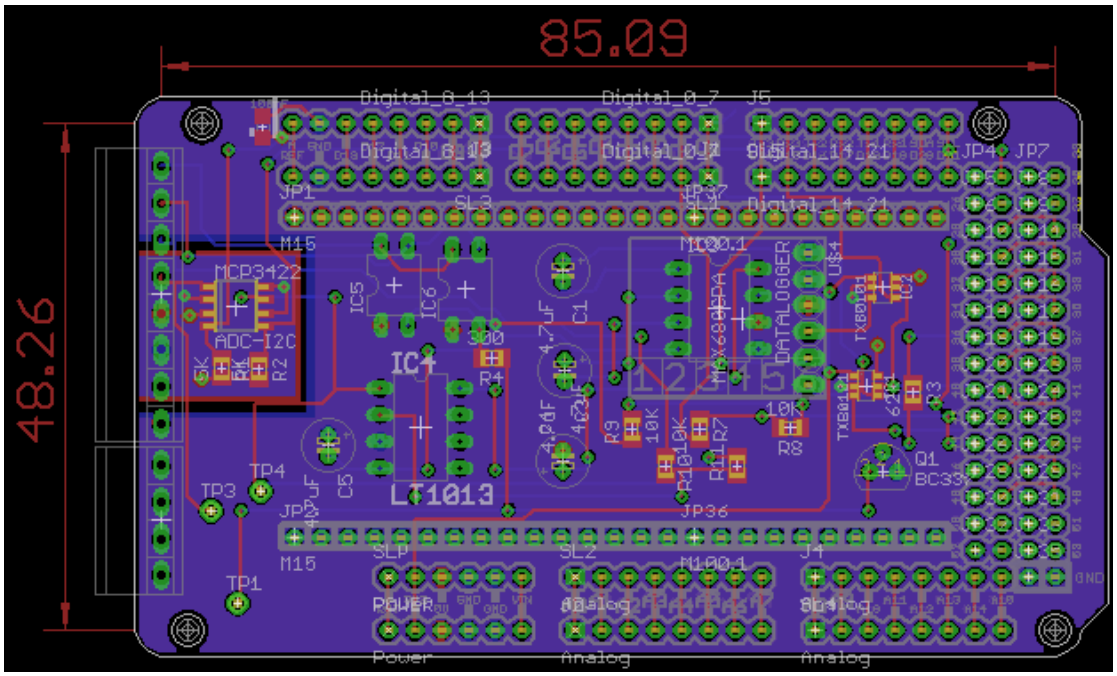


Figure 4.5-10 Stacked Sensor Board 2 (SB2)

Table 4.5-4 Stacked board 2

Component	V	Comm.	Information	Fig.
Data-logger "open-log"	5V	UART	Voltage level shifting for the TXO from 3.3V to 5V using level translator IC TXB0101	4.5-13
ADC "MCP3422" for AICs	5V	I^2C	5KOhm pull-up resistors inserted between the VCC and the SCL, SDA lines. CH1+ and CH2+ lines are connected with two separated pins of the terminal where will be attached the analogic output of the ion counters.	4.5-14
Solid state Relays AQY211EH paralleled	1.5V max	digital: high-low	Average 5mA each. A NPN BJT (bipolar junction transistor) "BC337" used for driving the relay load. The output pins of the relays will be connected to the tips of the pinch valves cable.	4.5-15
GPS level translator	5V	-	A voltage divider TXB0101 is used in order to change voltage from 3.3V to 5V for power and UART	4.5-16

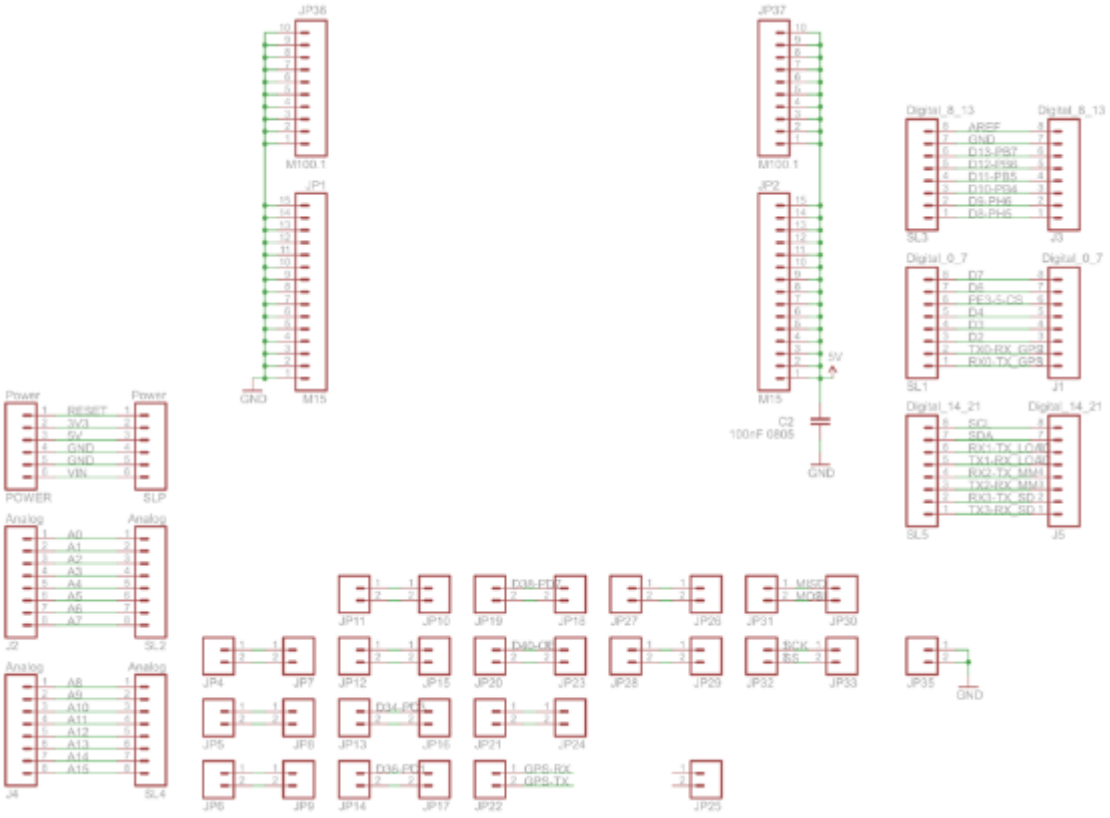


Figure 4.5-11 SB2 schematics pt. 1

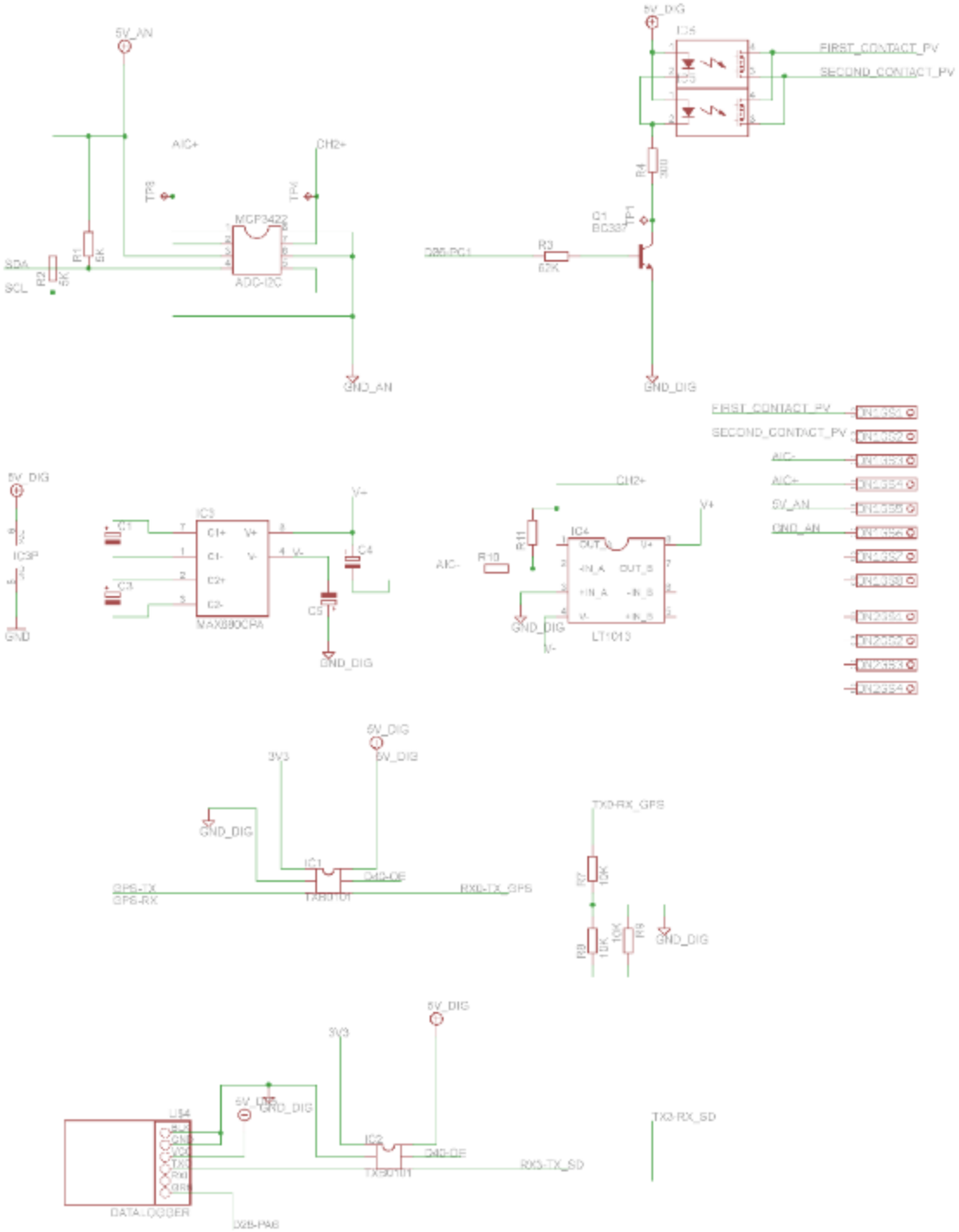


Figure 4.5-12 SB2 schematics pt. 2

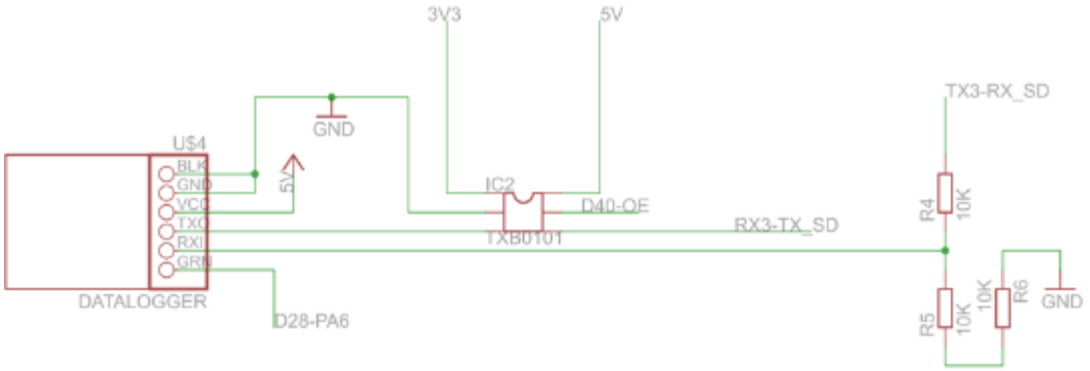


Figure 4.5-13 Data Logger schematics

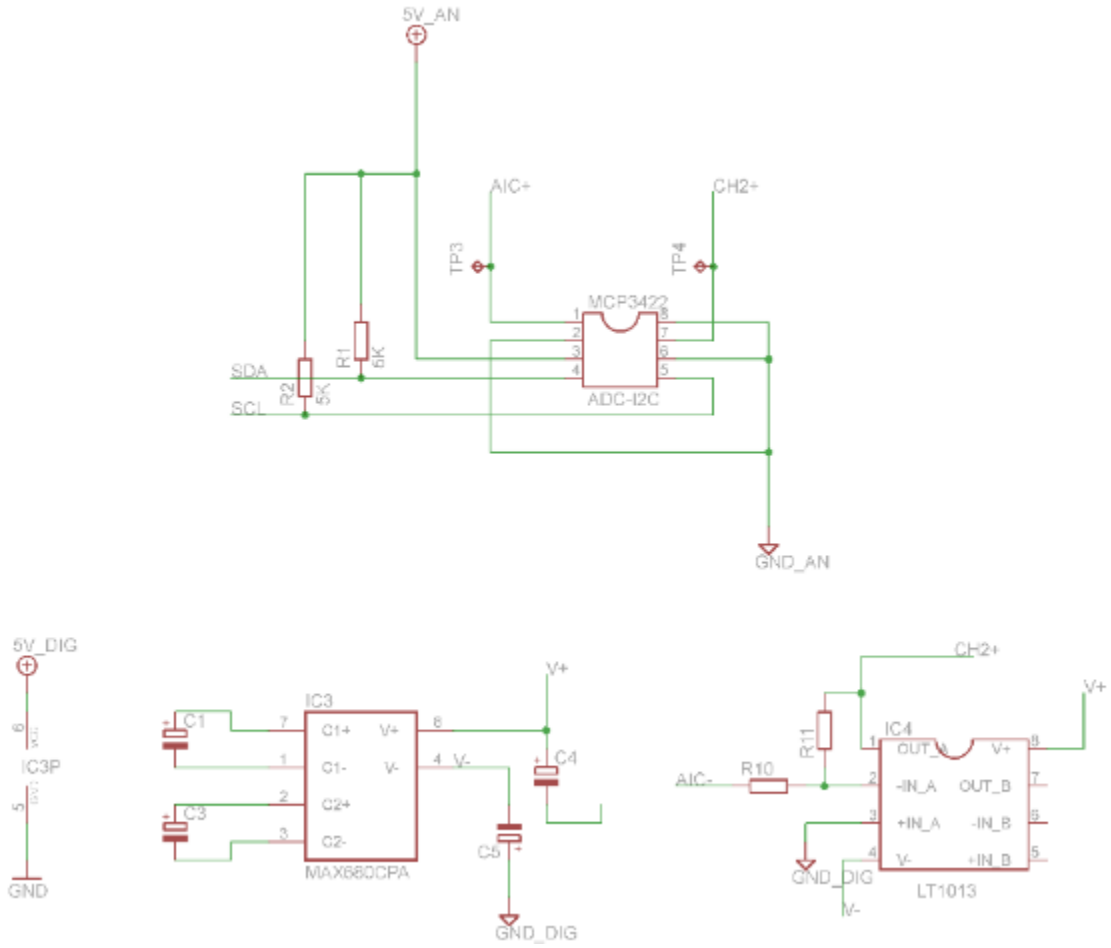


Figure 4.5-14 ADC schematic and signal conditioning circuit

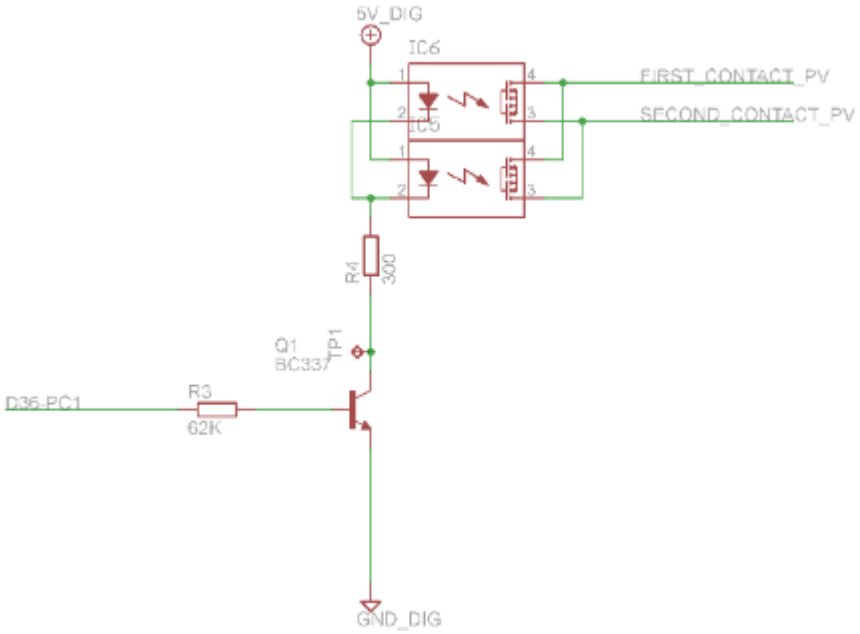


Figure 4.5-15 Paralleled solid-state relays' schematics

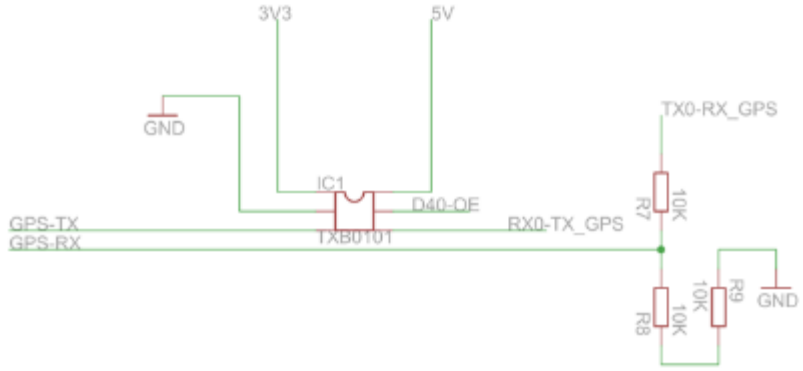


Figure 4.5-16 GPS level translator

4.5.4 Ethernet Shield

The Arduino Ethernet Shield allows an Arduino board to connect to E-Link. It is based on the Wiznet W5100 Ethernet chip that provides a network (IP) stack capable of both TCP and UDP.

The Ethernet shield connects to an Arduino board using long wire-wrap headers which extend through the shield. This keeps the pin layout intact and allows other shields to be stacked on top. Although for A5-Unibo Experiment the Ethernet Shield will be on the top.

The Ethernet Shield has a standard RJ-45 connection, with an integrated line transformer and Power over Ethernet enabled. There is an on-board micro-SD card slot that cannot be used simultaneously with Ethernet. A5-Unibo has decided to include another logger shield, Open-Log for data-logging.

It fits with the Arduino MEGA 2560 pin-out and the schematics are shown in Fig 4.5-17

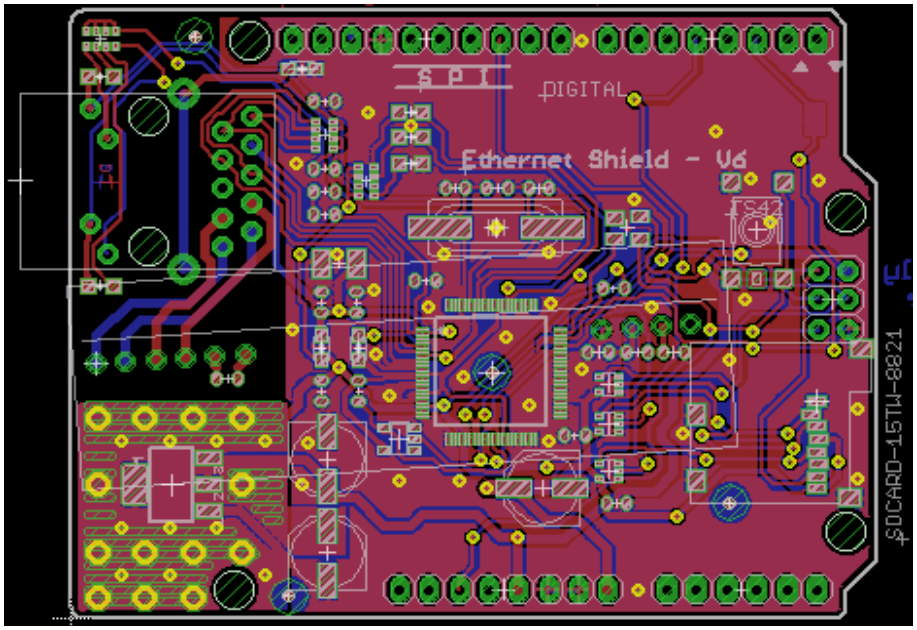


Figure 4.5-17 Arduino Ethernet Shield

4.5.5 Heaters Board (H-Board)

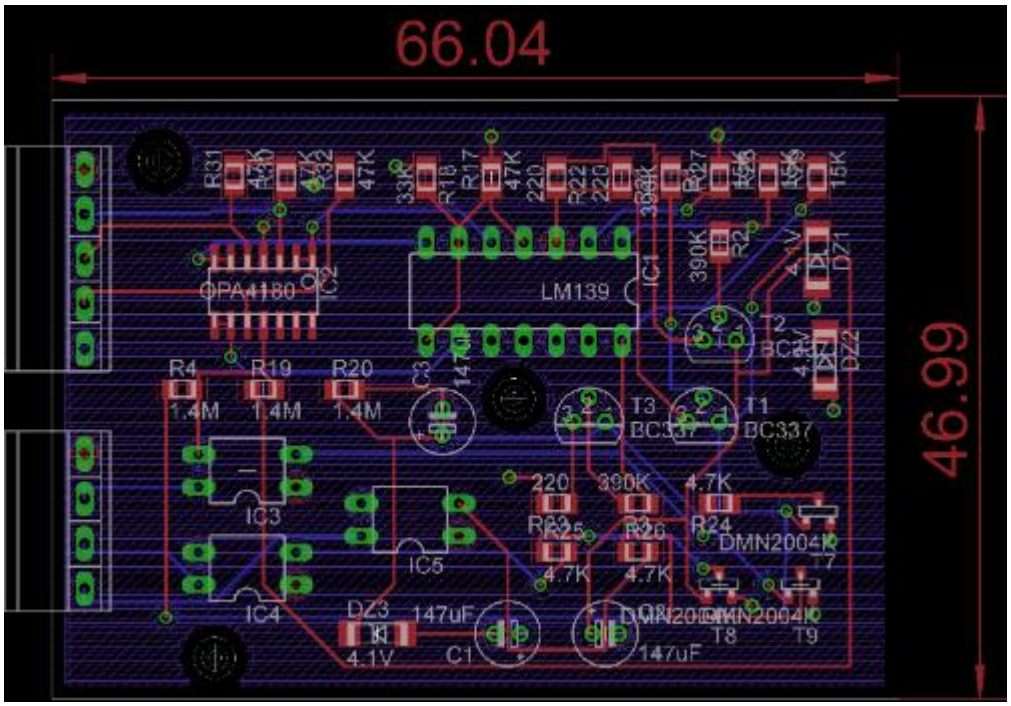


Figure 4.5-18 Heaters Board (H-Board)

A5-Unibo Thermal Subsystem requires an electronic control of the heaters. The H-Board is divided in two different parts: logical and control.

Regarding the **logical** part two fundamental ICs are distinguished:

- **OPA4180** quad operational amplifier: it is used as a buffer for voltage tracking. Its inputs are represented by the voltages coming from voltage dividers where each first resistor is made by a 47KOhm resistor and each second one is made by the thermistor "NTCLE100E3". (See figure 4.5-19)

- **LM139** quad comparator: it compares the voltage coming from the output of OPA 4180 with a reference voltage for 0°C. If the measured temperature gets below 0°C the signal goes up and becomes higher than the reference voltage. Thus the output of LM139 goes up to VCC and the control block (fig. 4.5-20) is activated. The parallel resistors in the right-high corner are pull-up resistors for the output of LM139.

The pair of diodes in the left-low corner are used to have a positive voltage not only for positive temperatures but also for temperatures below 0° C.

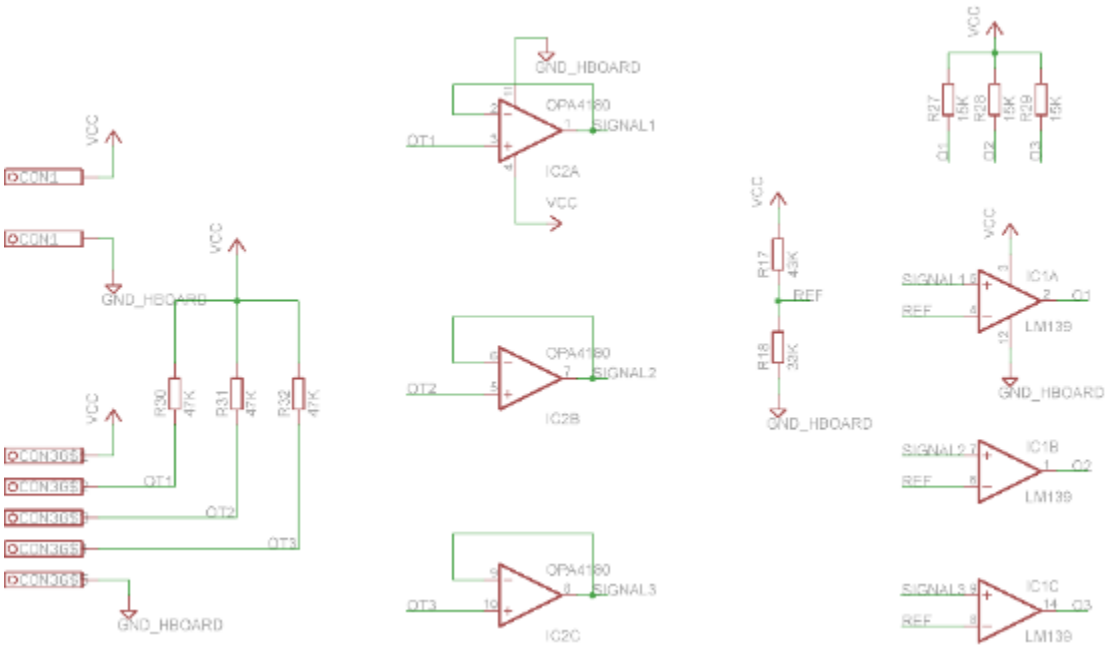


Figure 4.5-19 Logical block of H-Board

Regarding the **control** block:

Fig. 4.5-120 shows how the signal coming from the LM139 output (Ox: O1, O2, O3) is powered. For this purpose a BJT BC337, is used. When the signal “Ox” goes up, the three BJTs activate other three BJTs and in the meanwhile charge three 147uF polarized capacitors. Their function is to maintain the control block activated for about 75 seconds after 0°C is reached that is after Ox is grounded from LM139.

The three solid-state relays "AQY211EH" are used to switch on the heaters that need about 0.18A each

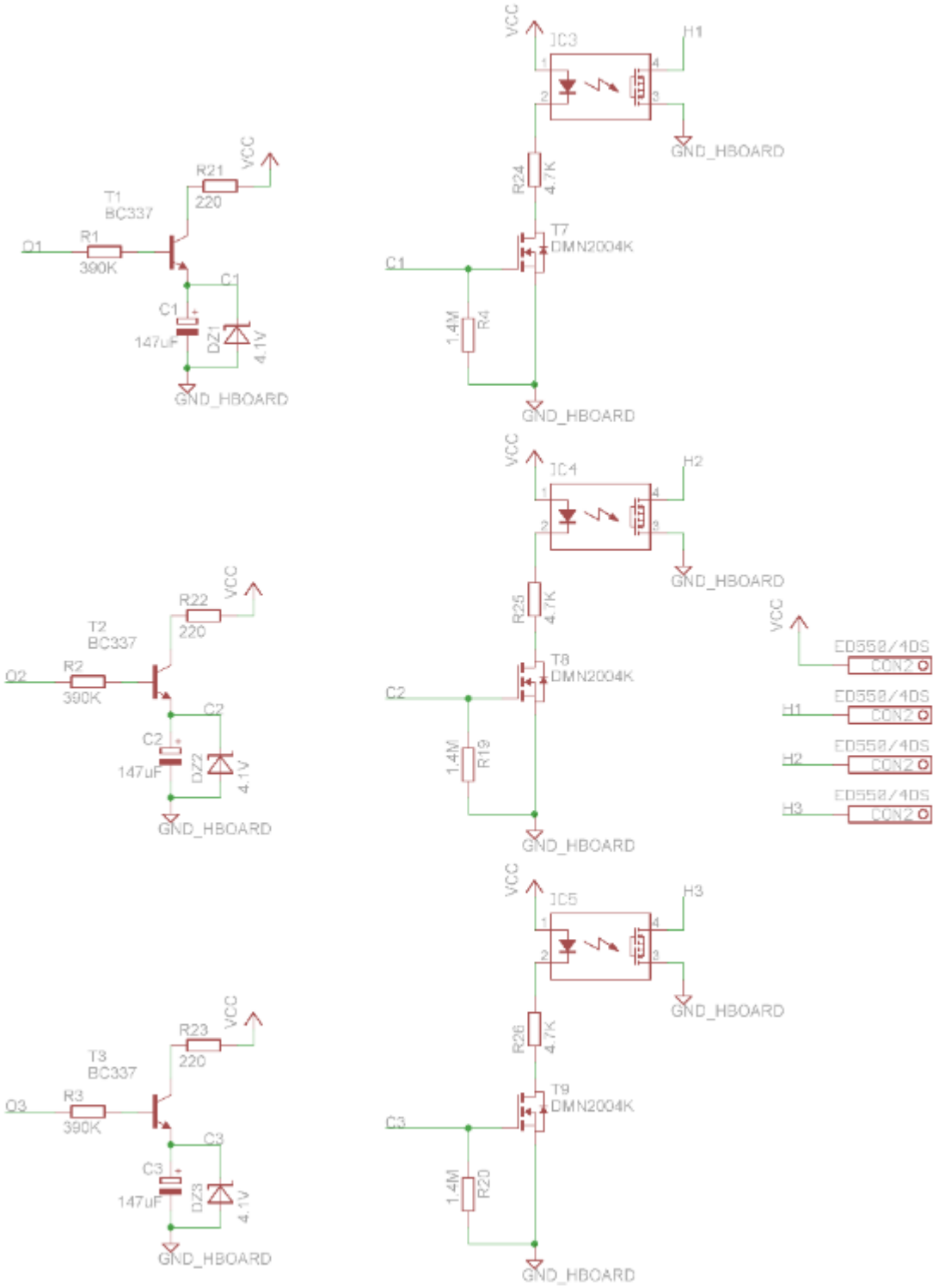


Figure 4.5-20 Control block of H-Board

4.5.6 Power control unit (PCU)

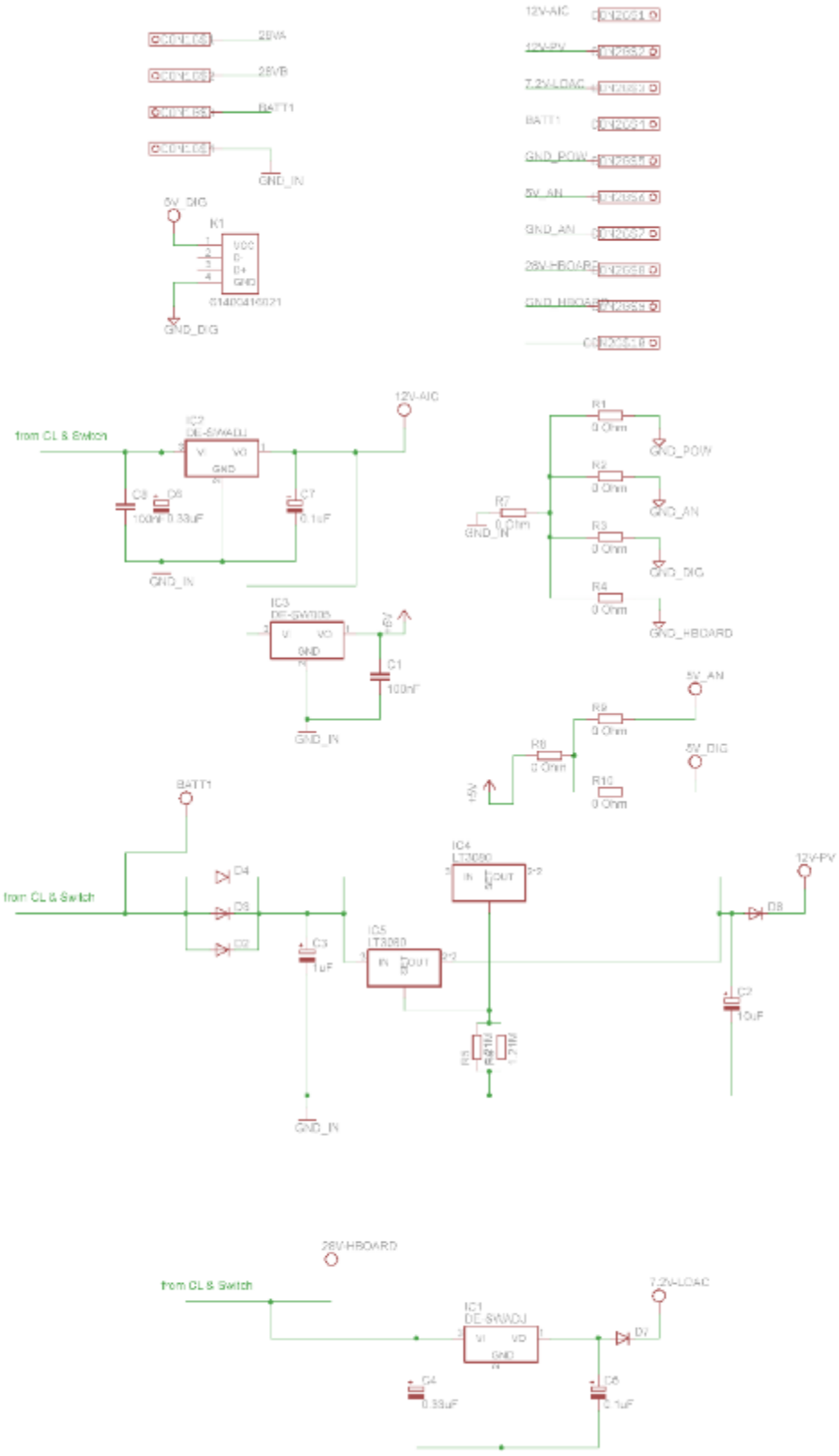


Figure 4.5-21 PCU voltage converting block

Fig 4.5-21 shows a schematic of the PCU board.

Three categories of ICs are shown:

- The first one is the variable switching voltage regulator DE-SWADJ that can give an output up to 25Watt.
- The second one is represented by fixed 5Volts switching regulator DE-SW005 that gives an output of 5V with a ripple lower than 2%, which is perfect for the electronic powering.
- The third one is represented by the variable linear voltage regulator LT3080 that has the potential to be paralleled.

Due to the different requirements for performing of the different instruments, the PCU has different power outputs:

- **Air ion counters:** 12V and 45mA provided by a switching voltage regulator DE-SWADJ
- **Electronic boards:** 5V and 500mA. For this purpose we have used the switching voltage regulator “DE-SW005”.
- **Pinch Valves:** 12 V needed and 0.33A of current each. Thus, two linear variable voltage regulators have been placed in parallel (“LT3080”) and three diodes in parallel in order to provide high output current.
- **Heater Board:** It will be powered by the 28V gondola battery without any voltage regulator.
- **LOAC**: It works at 7.2V and 450mA of current. For this purpose we have used the adjustable switching voltage regulator DE-SWADJ that regulates the voltage at 7.2V.

Figure 4.5-22 shows the schematic regarding the switching and current-limiting section of the PCU board.

For the **switching** of the three main power lines we used two different types of relays. For PL1 we used a "G5LA" relay that can quietly afford 4A of current. For PL2 & PL3 we've used a solid-state relay "AQY211EH" that allows the passage of 1A maximum of current. So in the 28V line two of them have been paralleled.

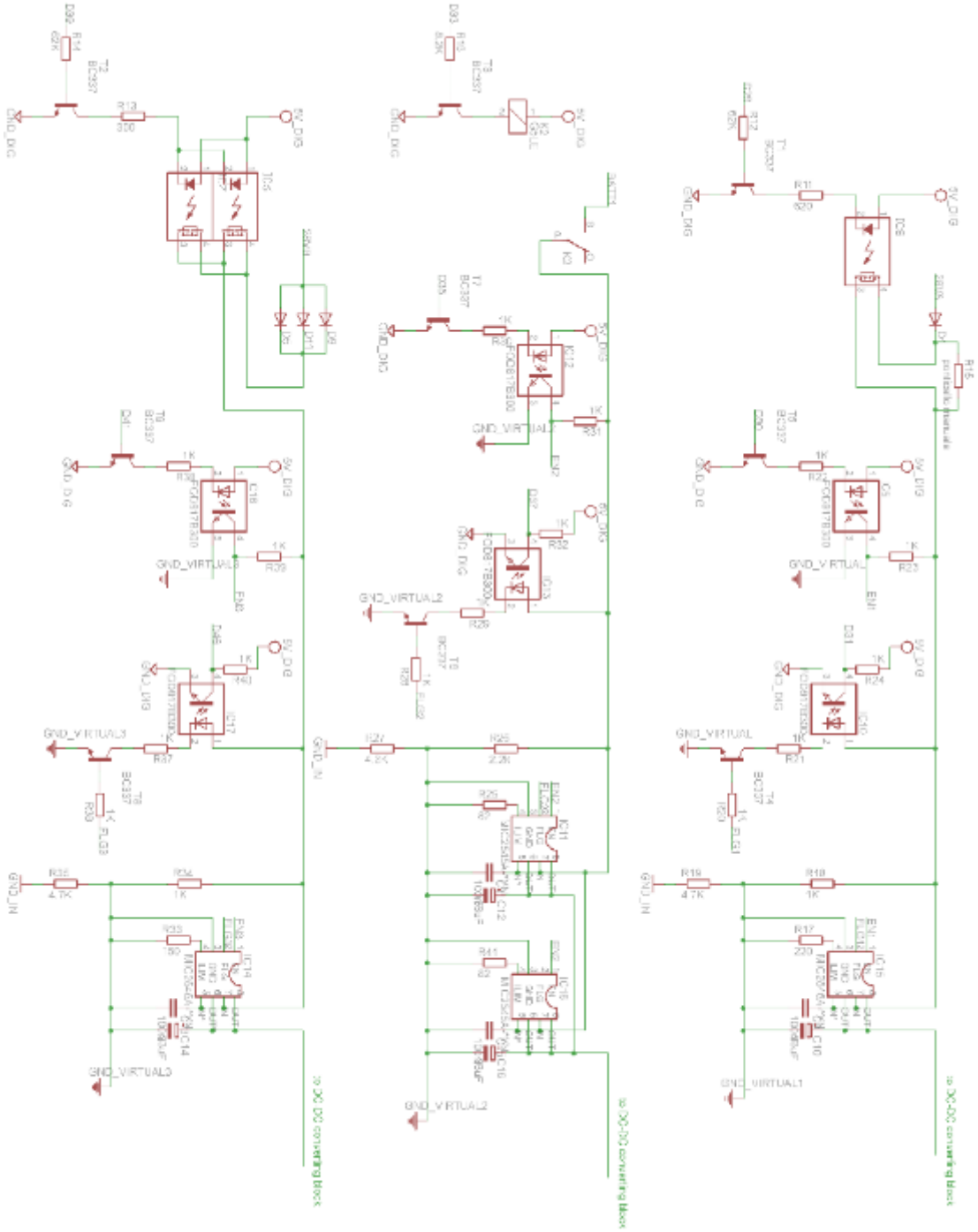


Figure 4.5-22 PCU Switch and Current-limiting block

For the **current-limiting** an IC of the type MIC2545A has been used due to its flexibility, since it has a wide choice of current limiting up to 3A.

Because of its supply voltage, which is between 2.7V and 5.5V, a voltage divider has been added considering possible current flows inside the IC. Verification test will be done.

Finally some photo-transistor opt couplers "FOD817 series" have been used in order to exchange signals from voltage referred to 'GROUND IN' and voltage referred to 'GROUND DIGITAL'.

Figure 4.5-23 PCU Board

Grounding strategy

The grounding strategy that will be implemented employs a star topology, in which each different category of instruments has its own line, and all the separate lines gather into a single point junction.

In fact, 4 different kinds of ground are used:

- Power ground
- Analogic ground
- Digital ground

• H-Board ground

This strategy is used in order to control the reference grounding levels for each instrument and avoid ground loops and reference fluctuations that could degrade output signals from the most precise instruments.

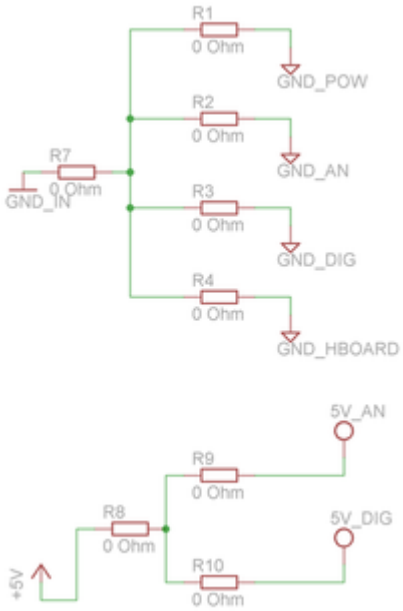


Figure 4.5-24 Ground scheme

4.5.7 Motion Mind Motor Controller.

In order to control the voltage given to the brushed DC motor of the 7502 BOXER Pump, a motor controller has been selected. The variation of flow and voltage of the PUMP is linear. Thus some test will be performed in order to know the precise flow at a certain pressure and the input voltage needed in order to obtain that flow.

Figure 4.5-25 M-M Motor Controller

Table 4.5-4 Motor Controller features

Features	
Current	Up to 9A continuous current (25A peak)
Voltage	6-24VDC brushed motors
Interface	Binary or ASCII control interface, RS232 or TTL signal levels, 19.2KBPS or 9.6KBPS
Control Modes	Serial PID based closed loop velocity,16 bit (requires encoder) Serial PID based closed loop velocity,32 bit (requires encoder) Analogic PID based closed-loop position,10 bit resolution analogic feedback
	Built in over-temperature, over-current, over-voltage, under-voltage protection

4.5.8 GPS Adafruit

After a wide research (Novatel, u-blox, etc), and due to budget reasons, A5-Unibo has selected this GPS Receiver because of its reliability and low cost. It has been tested in a HAB (High Altitude Balloon) up to 27 km high although Adafruit guaranteed up to 40 km altitude for some models.

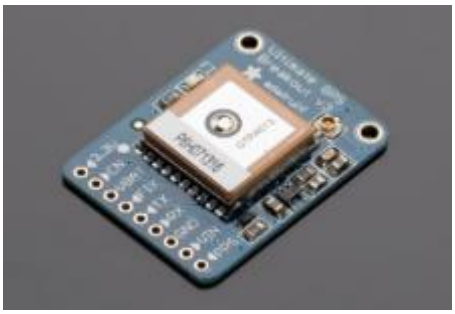


Figure 4.5-26 GPS Adafruit

Table 4.5-5 GPS features

Features	
Sensitivity	165 dBm, 10 Hz updates, 66 channels
Power	5V, 20mA current draw
Maximum Altitude	>25Km altitude (firmware up to 40km), tested at 27 Km
Satellites	22 tracking, 66 searching
Position Accuracy	1.8 m
Velocity Accuracy	0.1 m/s
Output	NMEA 0183, 9600 baud default

4.6 Thermal Design

Table 4.6-1 shows the allowable temperature range for each sensor of the experiment.

Table 4.6-1 Critical components' range

Instrument	T min	T max
Air Ion Counter	-50°	+50°
Particle Counter	-10°	+25°
Electronics	-20°	+50°
Batteries	0°	+50°

This section reports the description of the thermal model of A5-Unibo and the assumptions on which the thermal modelling is based. Two thermal cases – cold case and hot case – have been simulated. Boundary conditions for what concerns external temperature of air have been deduced by BEXUS10 flight.

4.6.1 Thermal model architecture

We performed transient analysis in order to evaluate the temperature inside the experiment as a function of the flight time.
The experiment control volume is filled with air at pressure and temperature variable with the altitude: it is a 0.36*0.45*0.40 mm^3 cube thermally insulated with respect to the external environment by means of 20 mm thickness polyurethane foam, characterized by a conductivity of 0.023 W/mK and by the following thermal-optical properties on both sides: $\alpha = 0.12$, $\varepsilon = 0.035$ (on the external surface a multi-layer aluminized film is applied). Physical properties of air have been deduced by the standard model of air. The experiment is placed on a 1.5 mm thickness Aluminum plate with a conductivity of 175 W/mK and conductively coupled with the gondola deck, which is approximated as a 20 mm thickness Aluminum plate. One internal node represent the air inside the box in order to evaluate the temperatures that each component can reach during the flight and so helping us to decide what kind of heating to use for the critical instruments. The plates and the insulating wall have been simulated as couples of diffusive nodes, in order to take into account the conduction through the material.

Nodes which are exposed to the external environment are thermally coupled with the sky background by radiation and external air by convection: sky background and external air have been simulated as boundary nodes.

Since the convection coefficient is unknown, a sensitivity analysis has been performed varying the convection coefficient value from 1 up to 9 W/m^2K.

In addition external nodes are subjected to solar flux, sky flux, albedo flux and planetary flux.

Nodes which face with the internal control volume are conductively coupled with internal air. The conductivity of the internal air has been computed as follows, according to the atmospheric model:

$$\lambda = \frac{2.64638 \times 10^{-3} T^{\frac{3}{2}}}{T + 245.4 \times 10^{-\frac{12}{T}}}$$

In addition internal nodes are mutually coupled by radiation.

The following figure is a schematic view of the overall architecture with the relevant heat exchange mechanisms (convection, conduction, radiation). The following 13 nodes are here represented:

External surface: 1
Inner surface: 2, 3, 4
Internal air up: 5
Inner plate up: 6
Inner plate down: 7
Internal air down: 8
Lower plate up: 9
Lower plate down: 10
Gondola plate: 11
Batteries: 12
Other instruments (masses + electronics): 13

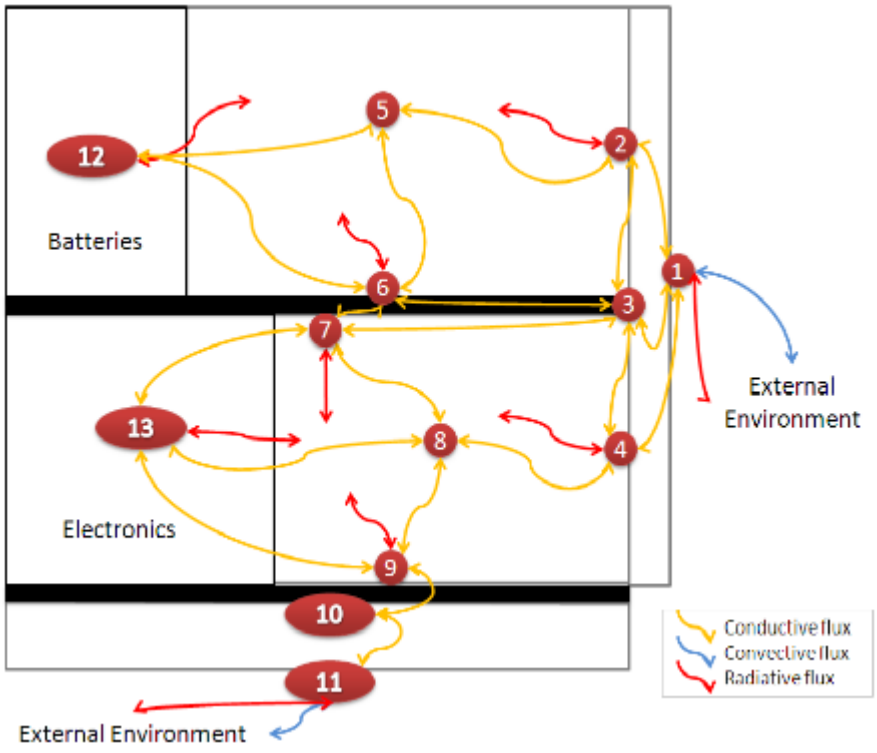
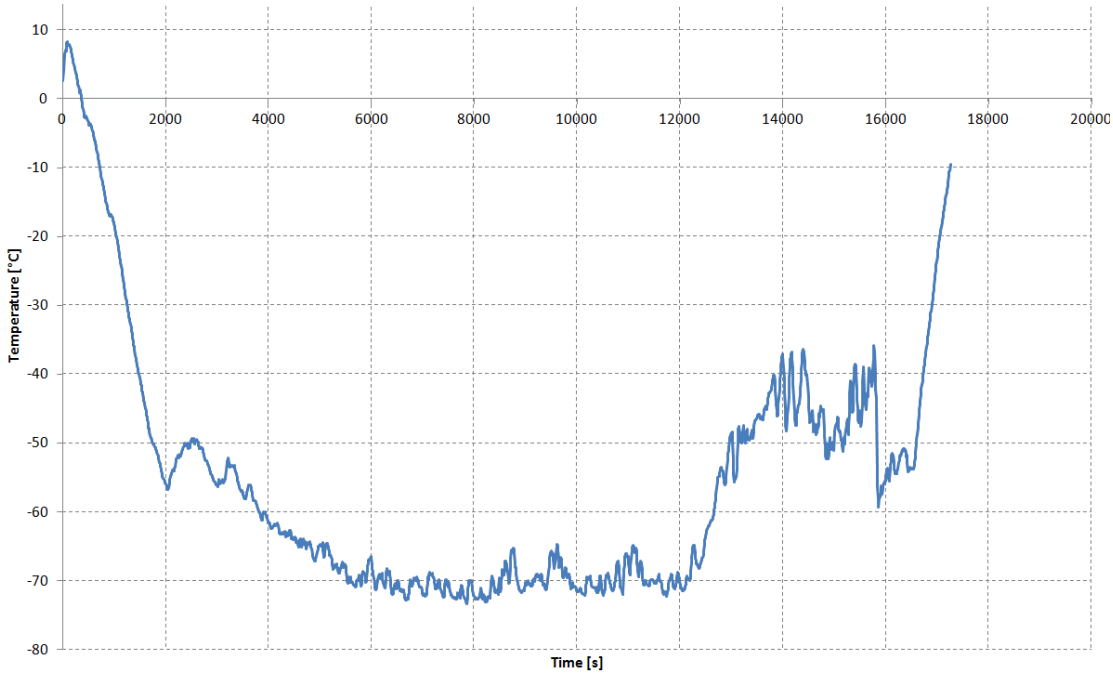


Figure 4.6-1 Thermal Node structure

4.6.2 Boundary conditions

The temperature of some nodes of the thermal model are known:

- The temperature of the Planet has been supposed equal to 283.15 K
- The temperature of the Sky is about 4 K.
- The external air temperature is known as a function of the time. The following graph shows the temperature profile versus time obtained during BEXUS10 flight, which has been taken as reference.



4.6.3 Solution

The temperature of the nodes results from a balance between thermal inputs (which cause an increase of the temperature) and thermal outputs (which cause a drop of the temperature). The thermal balance in steady state condition is given by the following relation, which contains the terms described above, taking into account the only contribution due to the radiation:

$$q_{SUN} + q_{ALBEDO} + q_{PLANET} + q_{SKY} = 0$$

In fact, the thermal regime is determined also by the conductive link between adjacent nodes *i* and *j*:

$$dq_{cond,i} = -\lambda \cdot dA_i \frac{T_i - T_j}{s}$$

Where: λ is the thermal conductivity of the material, *s* is the distance between the element's centre of mass, T_i and T_j are the temperatures of the adjacent nodes, and dA_i is the contact area between elements.

The thermal balance in steady state condition which takes into account both radiative and conductive contribution is:

$$q_{SUN} + q_{ALBEDO} + q_{PLANET} + q_{SKY} + \sum_i dq_{cond,i} = 0$$

Finally, transient analysis is performed considering an additional term, which represents the internal energy variation in time. The thermal balance equation in transient condition is:

$$q_{SUN} + q_{ALBEDO} + q_{PLANET} + q_{SKY} + \sum_i dq_{cond,i} = m \cdot c \cdot \frac{dT}{d\tau}$$

The term on the right represents the variation of the internal energy due to the thermal evolution: *m* is the mass of the system, *c* is the specific heat, $d\tau$ is the time lapse and *dT* the temperature variation in the elapsed time.

4.6.4 Results

In order to achieve the numerical solution for the problem a Matlab script has been implemented. Here we only display the final results but more details about the equations used in the thermal calculations can be found in appendix E

After the CDR we added in our calculations the airflow of pump and OPC as a possible source of heat loss. In particular a constant -10 W of heat loss through these instruments have been considered.

We computed the temperature for each of the air nodes and the batteries that are the most demanding components in term of thermal design. We also computed the analysis for 4 different scenarios:

- **Worst Cold Case 1 (WCC1)** = launch at night, with only 5W heating on batteries
- **Worst Cold Case 2 (WCC2)** = launch at night, with no heating on batteries and instruments.
- **Worst Hot Case 1 (WHC1)** = launch during the day, only 5W heating for the batteries;
- **Worst Hot Case 2 (WHC2)** = launch during the day, with 5W heating for the batteries and 10W heating for the other instruments

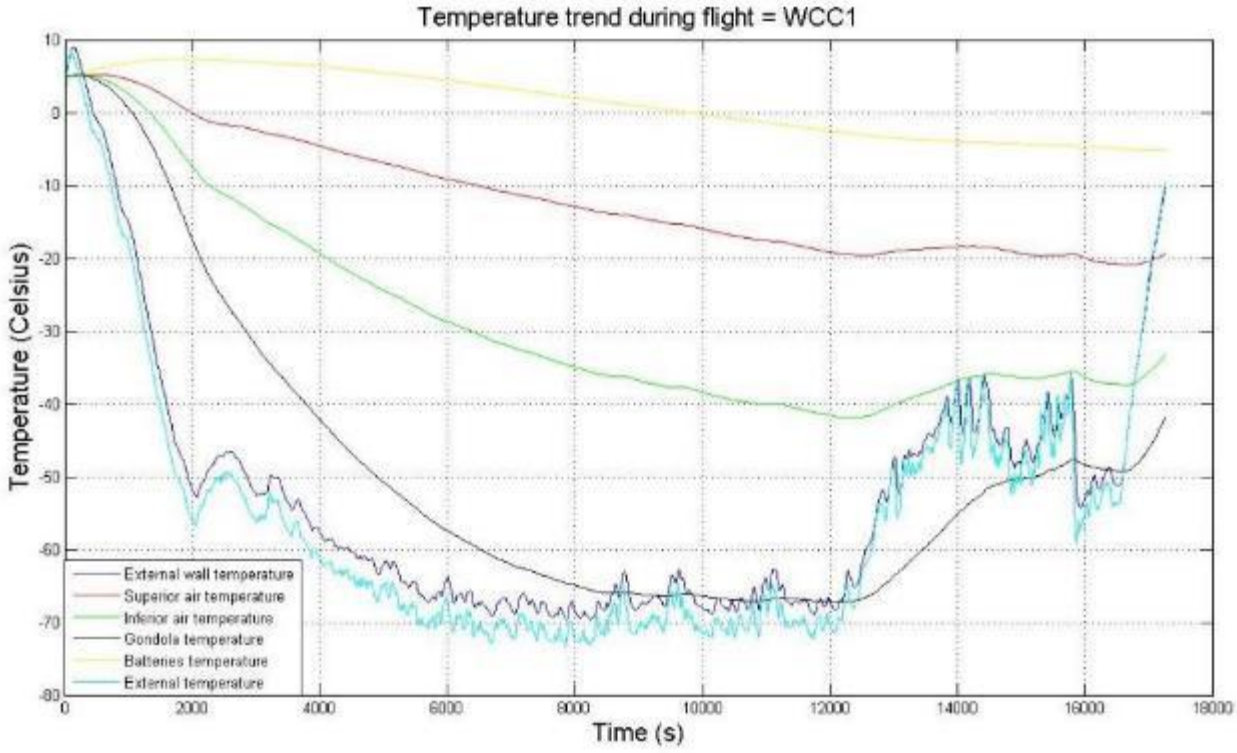


Figure 4.6-2 WCC 1

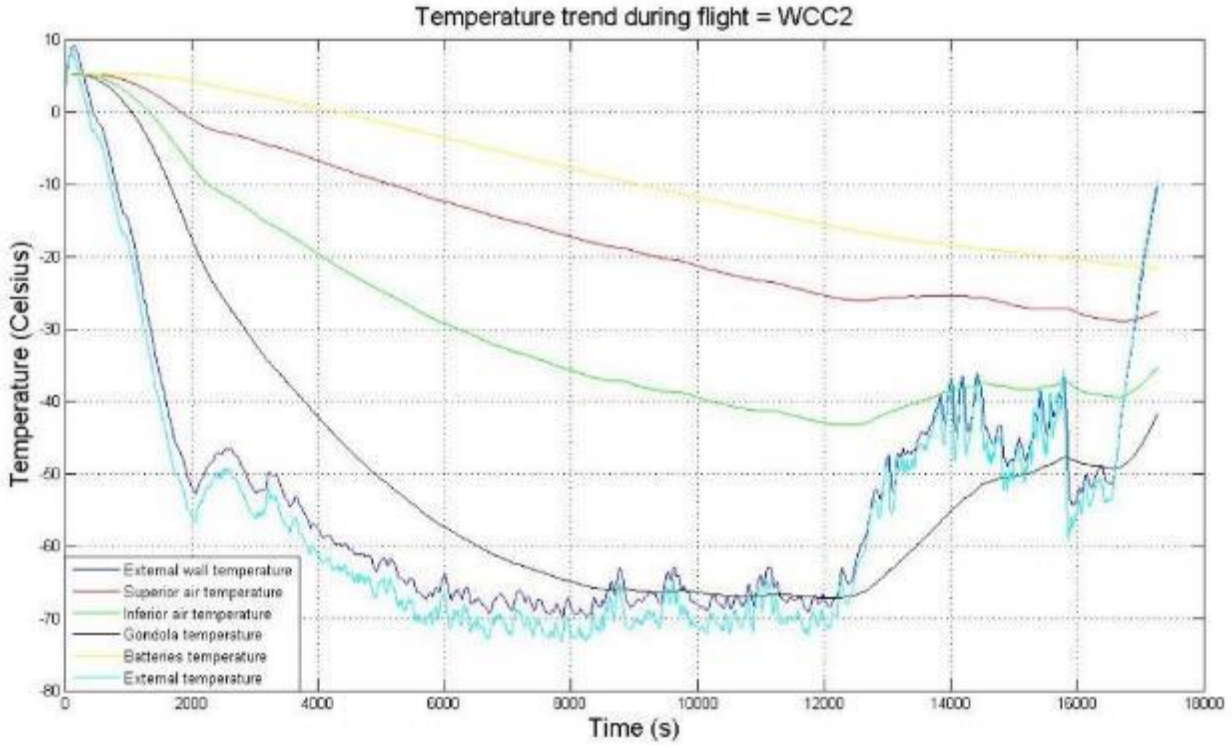


Figure 4.6-3 WCC 2

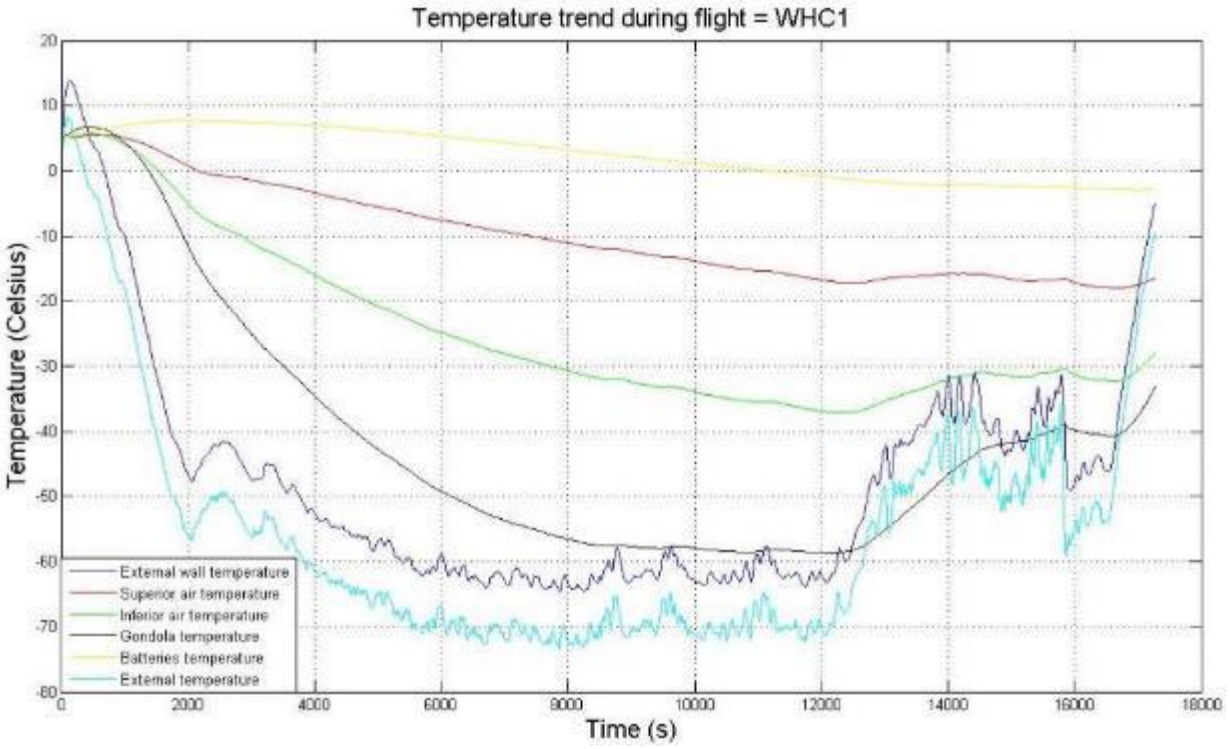


Figure 4.6-3 WHC1

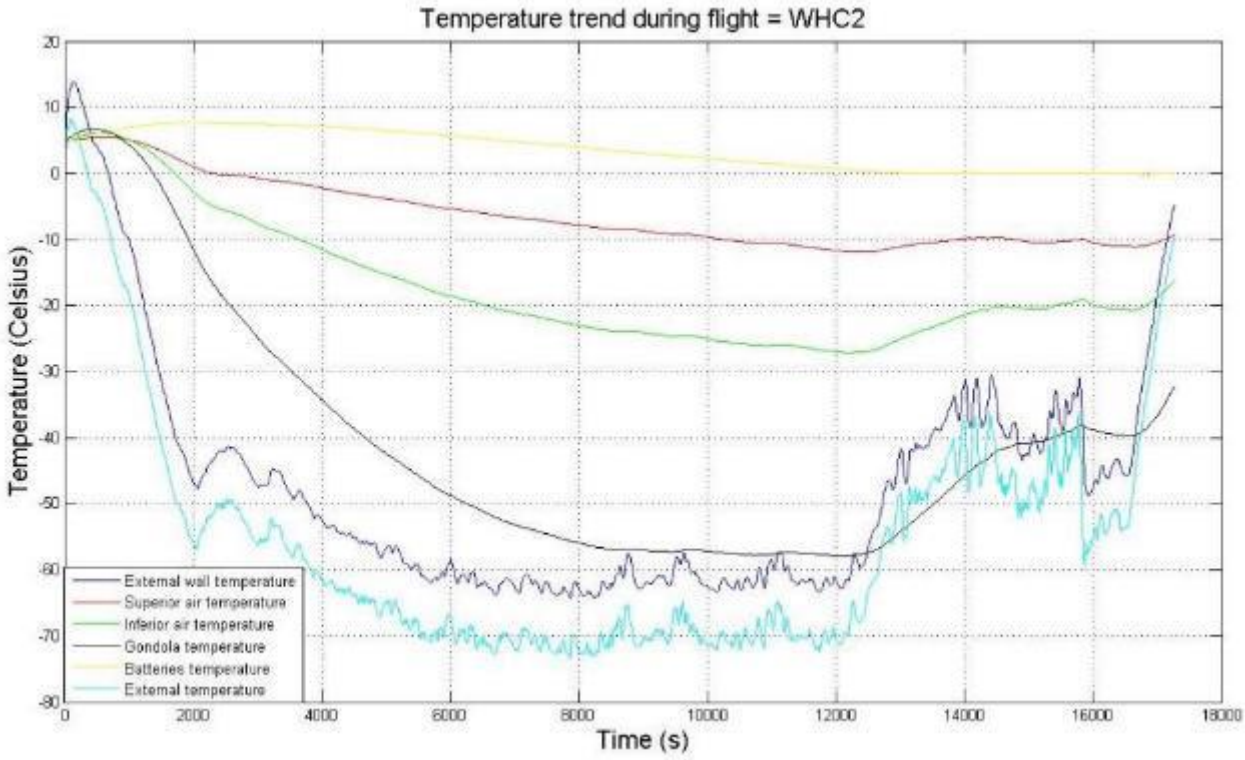


Figure 4.6-2 Worse Hot case 2

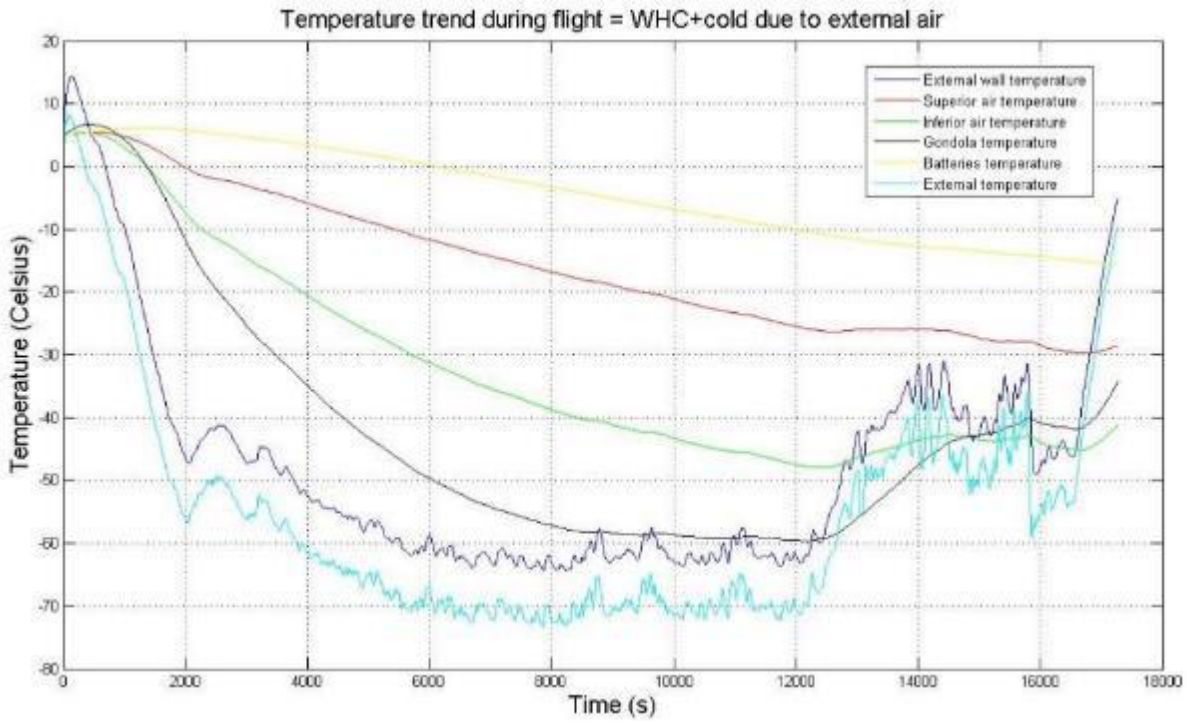


Figure 4.6-4 WHC + cooling due to airflow

4.6.5 Conclusions

From the previous simulations what we can conclude is that:

- Flight during the day is preferable. (and will be assumed from now on)
- Heating is needed for the batteries and a 5W amount is sufficient to keep the temperature within the desired temperature of 0° C.
- Electronics (superior air in graphics) never get below -10° C in WHC2 simulation, so heating will probably be unnecessary for ECU.
- Comparing WHC2 with WHC + cooling, which assume respectively a 10 W heating and a 10 W cooling for the instrument housing assembly (inferior air in graphics), we see that lowest temperatures vary between approximately -25° C and -48° C respectively. While the former is an acceptable value for almost all components, the latter is unacceptable, and hence, depending from the real cooling effect of the airflow, a total amount of heating required is between 10 W and 20 W. However, even in the worst case scenario the big safety margin in power budget allows us to increase the amount of heating to critical components.
- PT2 tests will help determine the heat generation by pump and hence the amount of external heat required.

4.7 Power System

The system is divided into three different power lines:

- **PL1** provides pump and pinch valves which have the highest power consumption;
- **PL2** feeds heaters and OPC;
- **PL3** feeds all the other instruments and the electronics.

The power is provided by two different sources:

- **BEXUS batteries** that provide power to PL2 and PL3. In particular two batteries will be put in parallel through the power board.
- **A5 battery pack,** which provides power to PL1 and is designed to match the high power request for this line.

We estimated the power budget for each one of the lines separately and consequently chose the best solution for the batteries taking into account performance, costs, and reliability.

4.7.1 Power Line One overview (PL1)

The power budget for this line was estimated considering the following assumption that represent a worst-case scenario:

- The pump is turned on at ground and kept at 6V for pre-launch and climbing phase (for a total of 3 hours) and at 12 V (maximum) for the sampling phase. PL1 is then turned off before the descending phase.

12 V is in fact the voltage required to obtain the maximum airflow of 32 l/min, which is much higher than the target flow of 9 l/min that we have to achieve during sampling phase. Vacuum chamber tests will determine what is the real voltage required to obtain this value in a low-pressure environment, and therefore allow a better estimation of the power consumption.

Table 4.7-1 Power line one (PL1)

Component	N°	Hours	Current	Voltage	Power	Total A	Total W	Total Wh
Pump	1	6	3 A	6 V (12V for 3 h)	18÷36 W	3 A	18÷36 W	162 Wh

100PDxNC12 Valves	4	3	0.33 A	12 V	4 W	1.32 A	16 W	48 Wh
ESC motion	1	7	0.024 A	15 V	0.36 W	0.025 A	0.36 W	2.52 Wh
12V LT3080	2	7	0.1 A	15 V	1.7 W	0.2 A	3.4 W	23.8 Wh
MIC25 49A	2	7	90 µA	5 V	450 µW	180 µA	900 µW	6.3 mWh
Switch G5LA relay	1	7	0.072 A	5 V	0.36 W	0.072 A	0.36 W	2.52 Wh
Total						**4.61 A**	**56.12 W**	**238.9 Wh**

Figure 4.7-1 shows the power consumption profile over time for PL1. As shown, the peak power consumption during sampling phase is approximately 56.12 W while the total energy consumed is 238.9 Wh. Since both these values exceed the performance of the Gondola supply, an external battery pack has to be used.

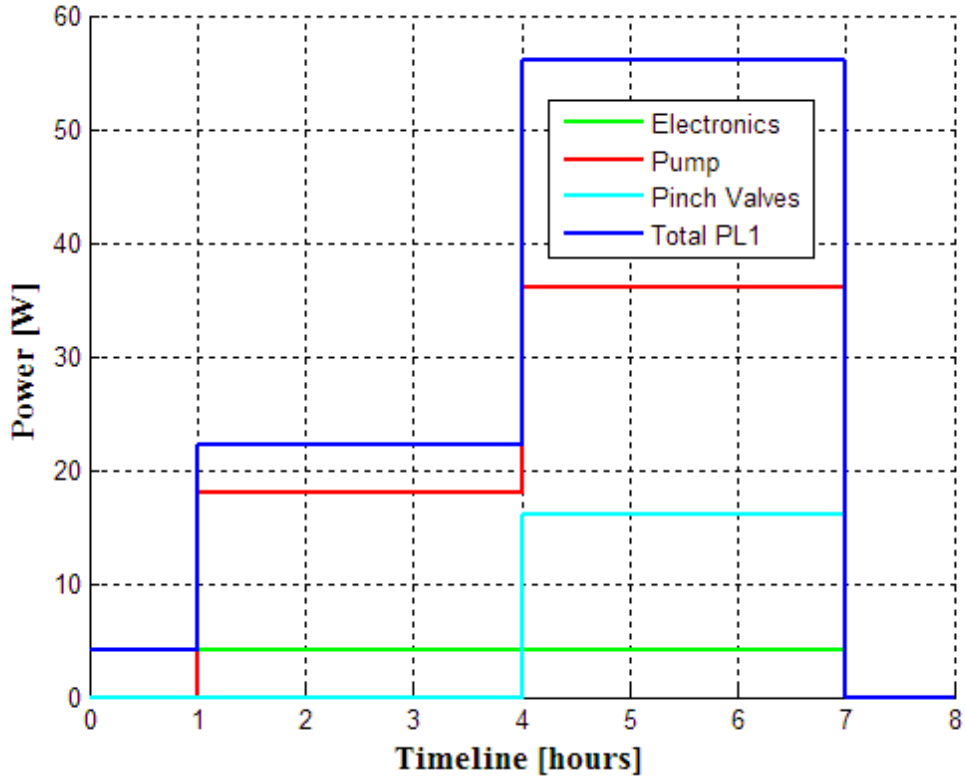


Figure 4.7-1 PL1 consumption profile

4.7.2 Power lines two and three overview (PL2 + PL3)

The power budget for these lines was estimated considering the following assumption:

- All the instruments are kept on for the whole duration of the flight with the exception of the descent phase (7 hours in total).

Table 4.7-2 Power line two (PL2)

Component	N°	Hours	Current	Voltage	Power	Total A	Total W	Total Wh
Heaters	3	7	0.33 A	28 V	5 W	0.178 A	15 W	105 Wh
Mosfet FDN306P	2	7	0.034 A	28 V	0.5 W	0.068 A	1 W	7 Wh
Optical Particle Counter	1	7	0.45 A	7.2 V	3.24 W	0.45 A	3.24 W	22.68 Wh
Temp. Sensor LM35DZ	3	7	60 µA	28 V	0.3 mW	180 µA	1 mW	7 mWh
Heaters AQY211EH	3	7	5 mA	1.5 V	7.5 mW	15 mA	22.5 mW	157 mWh
Switch AQY211EH	1	7	5 mA	1.5 V	7.5 mW	5 mA	7.5 mW	52.5 mWh
7.2V DS-SWADJ	1	7	60 mA	28 V	1.7 W	60 mA	0.8 W	5.6 Wh
LM139	1	7	5 nA	28 V	72 nW	5 nA	72 nW	50 µWh
MIC25 49A	1	7	90 µA	5 V	450 µW	90 µA	450 µW	3.15 mWh
Trans BC337	3	7	22 mA	28 V	0.62 W	66 mA	1.87 W	13.1 Wh
Total						**0.842 A**	**21.94 W**	**153.59 Wh**

Table 4.7-3 Power line three (PL3)

Component	N°	Hours	Current	Voltage	Power	Total A	Total W	Total Wh
Arduino Mega	1	7	0.04 A	5 V	0.48 W	0.04 A	0.48 W	3.36 Wh

Ethernet Shield	1	7	0.1 A	5 V	0.5 W	0.1 A	0.5 W	3.5 Wh
GPS	1	7	25 mA	3.3 V	82 mW	25 mA	82 mW	574 mWh
Air Ion Counter	2	7	0.045 A	12 V	0.54 W	0.09 A	1.08 W	7.56 Wh
P. sensor MS5607	1	7	4 µA	3.3 V	48 µW	4 µA	48 µW	336 µWh
T. sensor DS18b20	1	7	4 mA	5 V	20 mW	4 mA	20 mW	140 mWh
H. sensor HIH9120	1	7	1 mA	5 V	0.012 W	1 mA	12 mW	84 mWh
Valves AQY211EH	1	3	5 mA	1.5 V	7.5 mW	5 mA	7.5 mW	22.5 mWh
12V DE-SWADJ	1	7	57 mA	28 V	1.6 W	57 mA	1.6 W	11.2 Wh
5V DE-SW005	1	7	0.1 A	12 V	1.2 W	0.1 A	1.2 W	8.4 Wh
3.3V L78L33*	1	7	5 mA	5 V	N.S.	5 mA	N.S	N.S.
ADC MCP3422	1	7	134 µA	5 V	670 µW	134 µA	670 µW	4.7 mWh
Trans BC337	4	7	22 mA	28 V	0.62 W	22 mA	2.48 W	17.36 Wh
Communication P. sensor**	1	7	8.6 µA	5 V	43 µW	8.6 µA	43 µW	0.3 mWh
MIC25 49A	1	7	90 µA	5 V	450 µW	90 µA	450 µW	3.15 mWh
Switch AQY211EH	1	7	5 mA	1.5 V	7.5 mW	5 mA	7.5 mW	52.5 mWh
Total						**0.454 A**	**7.47 W**	**52.26 Wh**

*N.S. = Not Specified
** valued on 10 ms every 10 s

Figure 4.7-2 shows the power consumption profile over time for PL2 and PL3. The total power consumption has an almost constant value of 29.41 W, while the total energy spent is approximately 205.85 Wh. Since these values exceed the performance of a single battery pack of the Gondola supply, we asked for two battery packs, which will be put in parallel through the PCU.

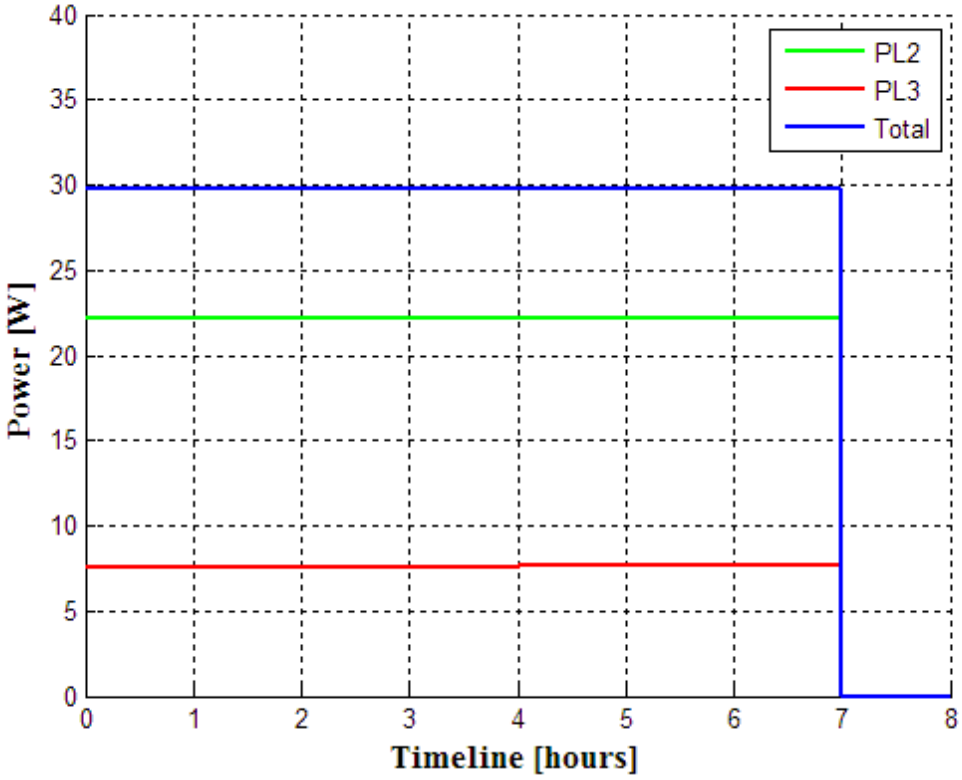


Figure 4.7-2 Consumption profile for PL2 and PL3

1.1.4 A5 Battery Pack

A5 battery pack consists of three series of four MP 176065 Integration SAFT, capable of providing 15 V, 306 Wh nominal energy and 20.4 Ah of capacity. This battery pack was designed to feed PL1, which has a high demand in terms of power and could not be supplied by the BEXUS battery alone. Moreover, the use of separated batteries for the two lines ensures a better insulation between the different components of the experiment.
A scheme of A5 battery pack is shown in figure 4.7-3.

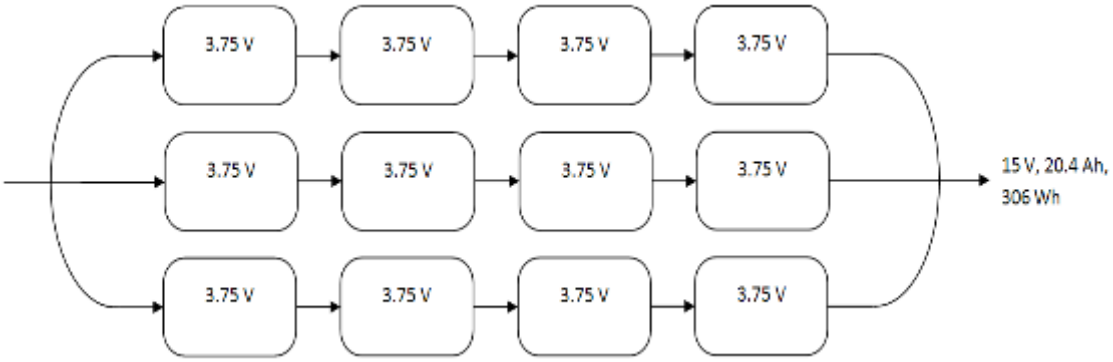


Figure 4.7-3 A5 battery pack

The weight of each battery cell is 143 g, while the total weight of the battery pack is approximately 2 Kg, also considering cover and heaters.

Batteries' performances degrade at low temperatures (see MP-176065 Datasheet). To compensate for this effect we will install foil heaters in each sub-pack to keep their temperature close to 0˚C and ensure sufficient available power for experiment.

Since the chosen batteries are rechargeable, we do not need to buy more than one battery pack for the tests. In total, we need to buy:

- One "flight" battery pack;
- One battery pack for tests and for possible launch delays.

Tables 4.7-4 and 4.7-5 respectively show the overall performance required by PL1 and PL2 + PL3, compared to the nominal values supplied by the battery packs. As shown, the safety margin in large for both the solutions adopted, giving us both operational margin and reliability.

Table 4.7-4 PL1 overview

	Current	**Power**	**Energy**
PL1	4.61 A	56.12 W	238.9 Wh
A5 Battery pack	21 A (max. discharge for the three series in parallel)	315 W (max.)	306 Wh
Safety Margin			**21.9 %**

Table 4.7-5 PL2 + PL3 overview

	Current	**Power**	**Energy**
PL2 + PL3	1.296 A	29.41 W	205.85 Wh
Gondola supply (two batteries)	2 A	56 W	364 Wh

Safety Margin			**43.4 %**

4.7.3 Power Control Unit (PCU)

Figure 4.7-4 shows a logical scheme of the PCU. Black arrows represent the power lines, while blue arrow represents the serial communication used to regulate ESC Motion. Moreover, the Pinch Valves supply passes through the electronics where it is controlled by a relay.

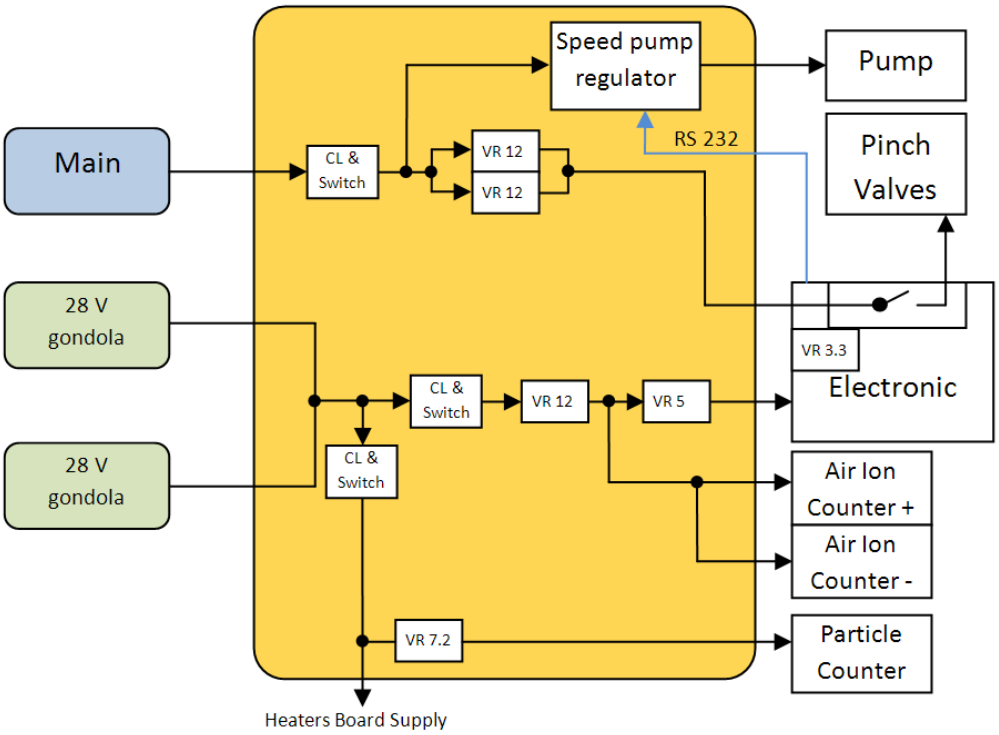


Figure 4.7-4 Logical scheme of the PCU board

- A5 battery pack provides 15 V and needs to be regulated down to 12V for the pinch valves, while ESC Motion Mind motor controller will regulate the voltage supply for the pump.
- The gondola batteries, which supply the instruments and electronics, provide 28 V and need to be regulated down to: 12V for both AICs, 7.2V for OPC, 5V for electronic components and 3.3V for GPS and pressure sensor.

Voltage Regulators

Switching regulators are more efficient if compared to linear voltage regulators although they create more noise, therefore they are used to regulate 28V down to 12V and 7.2V. Switching regulators are used to regulate 12V down to 5V. To regulate 15V down to 12V for pinch valves we use two linear regulators in parallel while to regulate 5V down to 3.3V for the Pressure Sensor and the GPS we use a low dropout regulator.

Therefore, our PCU uses a combination of switching and linear voltage regulators. Regulators are used in cascade to allow minimum power dissipation.

Figure 4.7-5 shows a logical scheme of the heaters' board, where black arrows represent power lines and blue arrows represent the data transmitted from temperature sensors.

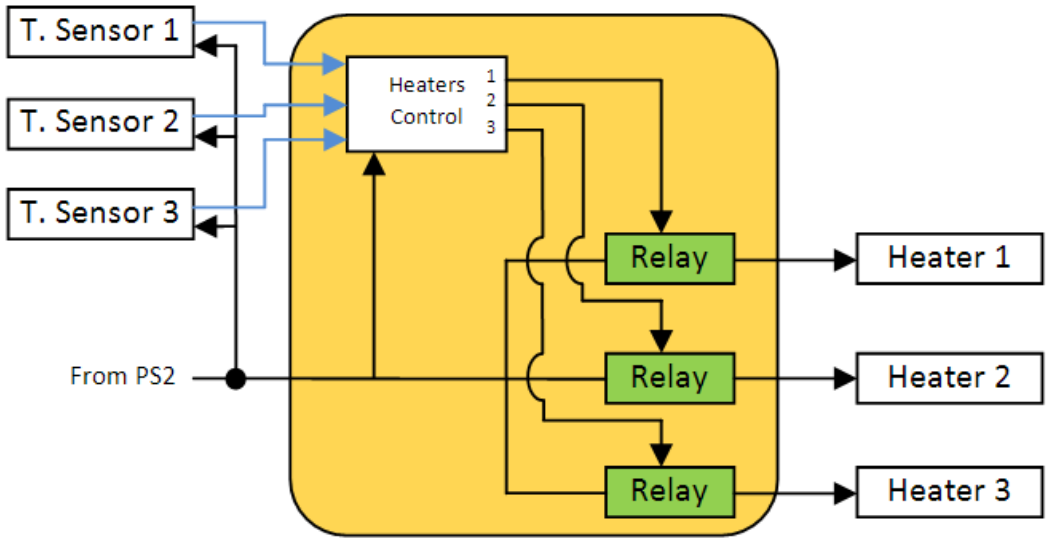


Figure 4.7-5 Logical scheme Heaters' board.

4.7.4 Safety issues and solutions

Each power line is equipped with a current limiter (CL) to prevent overconsumption in case of failure of some instruments, and to ensure the possibility of recovery for the system (in opposition to fuses). We can control the current and turn off the instrument or the whole line in an attempt to reset the instrument itself or the Arduino MEGA buffer.

As current limiters, we use MIC25-45A for all power lines. In particular, the high current consumption of PL1 needs to be regulated with two parallel CLs. In total, we employ four CLs on the PCU board.

Moreover, we need to consider that a hard impact or water landing could cause damage to the pump and possibly an explosion (if still on) and, subsequently, a contamination of the samples or a loss of stored data. To avoid this we

decided to turn off the whole experiment prior to the descending phase. This done employing a solid-state relay for PL2 & PL3, and a G5LA relay for PL1.

4.8 Software Design

4.8.1 Requirement Analysis

The software overall design should keep all the tasks requested by the software requirements in consideration. Error handling is necessary to have a reliable on-board software.

All processes should be monitored to prevent unpredictable behaviour by handling errors, exceptions or bad data. Furthermore they have to be supervised regarding the execution time, using a timeout to end a task without creating long delays in the life cycle.

Regarding inputs acquisition, it is important to underline that altitude detection is performed twice: the most reliable and accurate measurement is provided by a GPS, but in case of failure of this device, the altitude is obtained from pressure measurement (Failure Detection, Isolation and Recovery approach is being considered to reach that).

The main parts of the control software are divided into functional groups, one for each of these specific tasks:

1. Monitor status and parameters of the components.
2. Monitor altitude readings (both from GPS and pressure sensor) to control the status of the experiment. In particular it is required to:
   - Open valves in the SU once the established altitude is reached.
   - Close valves in the SU when a set displacement from established altitude is reached.
3. Handle communication with GS.
4. Store critical data in internal flash memory.

4.8.2 Operating modes

Autonomous Mode

Default mode.

Autonomous functions (no user action requested).

All collected data are send to GS.

Ground Station Acknowledgement (GS-ACK) Mode

System switches from Autonomous Mode when it needs a confirmation.

System waits for the user's answer for a given amount of time, then it automatically switches back to Autonomous Mode.

Manual Mode

Requested by GS to force a command when a failure or error arises. This mode can be seen as a Task Manager to handle directly with the source of the trouble or to prevent it.

Both Autonomous and Manual modes should be equally able to perform the whole mission, providing ECU to be completely independent in case of connection loss. However, whatever mode is set, the system automatically provides to switch to Autonomous Mode after a timeout occurs (2 min without commands) to prevent the system from remaining locked in Manual mode while E-Link connection does not work.

As long as Arduino is used, implementation of the software will be developed in C/C++. The ground segment software is developed using LabVIEW

4.8.3 Software System Architecture

Subjects expected in the system:

- **OBDH**: the A5 experiment deployed on gondola.
- **GS**: the Ground station.

Messages exchanged between *subjects*:

- *SetValues* (cmd=1,)
- *Ack* (cmd=2)
- *ConfirmRequest* (cmd=3)
- *ConfirmResponse* (cmd=4)
- *StatusUpdate* (cmd=5)

Interactions between *subjects* of the systems are better expressed using particular keyword to describe them:

- *SendUpdate*: OBDH **dispatches** StatusUpdate to GS
- *SendCmd*: GS **asks** SetValues to OBDH, OBDH **confirms** (Ack message)
- *AskForConfirm*: OBDH **requires** ConfirmRequest to GS, GS **replies** with ConfirmResponse

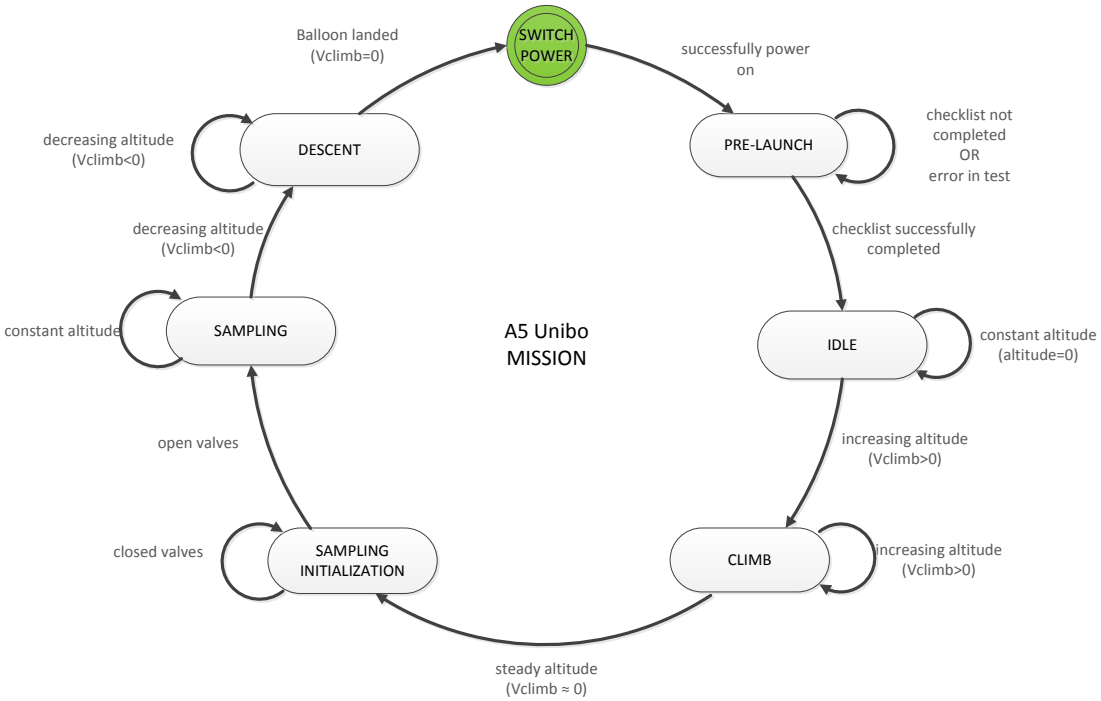
Where the semantic of the highlighted keyword is:

- *Dispatch:* refers to a one-to-one asynchronous communication where the sender expects the message to be received by recipient.

- *Ask:* refers to a one-to-one asynchronous communication where the sender expects to receive a “message received” confirmation by the application layer of the recipient.
- *Require:* refers to a one-to-one asynchronous communication where the sender expects a “reply message” from the recipient.

4.8.4 Mission States

The mission is performed in a series of following steps. To correctly perform them the software itself is divided into a certain number of states. Each state represents a specific step of the mission and requests its own specific routine to be correctly performed. The mission will be successful if no state will fail. The successful completion of one state is the essential requirement to pass to the following one. This kind of behaviour is the most likely and desired. Nevertheless some shortcuts are necessary to make the system to be a real state machine. Therefore the software should manage to switch from a state to another one (not necessary the following one). In Manual Mode this is simply requested by user using a dedicated button that activate on-board software changing in status phase. In principle this command is available also for the Autonomous Mode since a shortcut exists.



Pre-Launch

Enter condition: Main power on

Exit condition: All tests successfully passed

Operating Mode: Manual

Description: Pre-Launch state is a checklist (“go/no go”) of the functions that need to be performed to initialize the instruments (Starting sequence, calibration, test, etc.). Each instrument is powered on and successfully tested (first of all GS communication). If the component is properly working the checklist goes on, otherwise an error arises and the component is restarted or fixed.

System components	Status
Communication links	ON
Sensors	ON
Data-loggers	ON
Valves	ON
Pump	ON
Air Ion Counters	ON
Particle Counter	ON
GPS	ON

Table 4.8-1 Pre-launch state

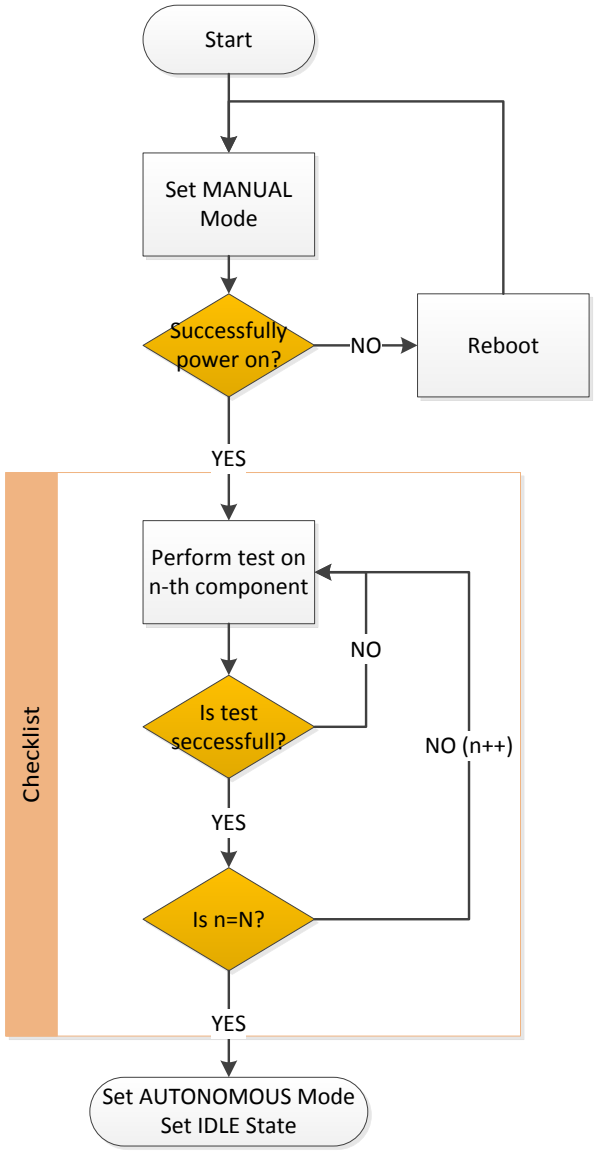


Figure 4.8-1 Pre-launch state

Idle

Enter condition: All tests successfully passed

Exit condition: GS submits a request for launch or the altitude starts increasing

Operating Mode: Manual

Description: In Idle state ECU is in a stand-by status in which power consumption is reduced to minimum levels nevertheless GS communication, GPS and AICs still operate. Idle phase is left after GS request or if GPS detects a significant increase in altitude.

System components	Status
Communication links	ON
Sensors	OFF
Data-loggers	OFF
Valves	OFF
Pump	OFF
Air Ion Counters	ON
Particle Counter	OFF
GPS	ON

Table 4.8-2 Idle state

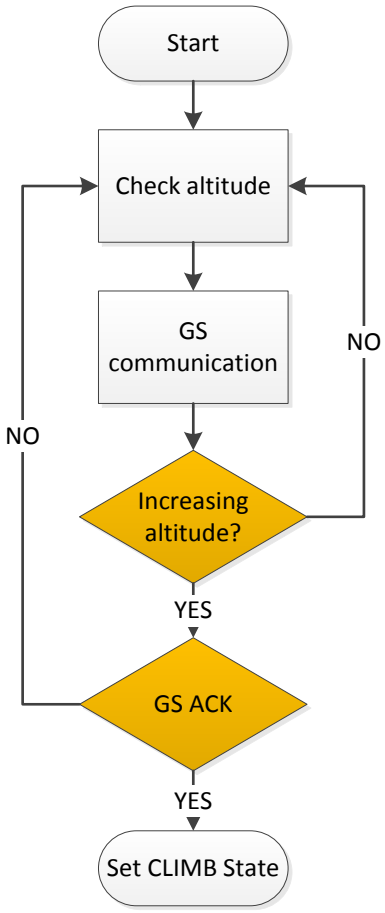


Figure 4.8-2 Idle state

Climb

Enter condition: GS submits a request for launch or the altitude starts increasing

Exit condition: Experiment nominal altitude is reached

Operating Mode: Autonomous / GS-ACK

Description: All parameters are monitored, sent to GS, and logged on the internal SD. Once a pre-set altitude is reached (about 25 km), a confirmation is requested to GS and the operating mode is switched to GS-ACK. If acknowledgment is obtained or a timeout occurs this stage is concluded and the system advances to the following step entering back in Autonomous Mode.

System components	Status
Communication links	ON
Sensors	ON
Data-loggers	ON
Valves	OFF
Pump	ON
Air Ion Counters	ON
Particle Counter	ON
GPS	ON

Table 4.8-3 Climb state

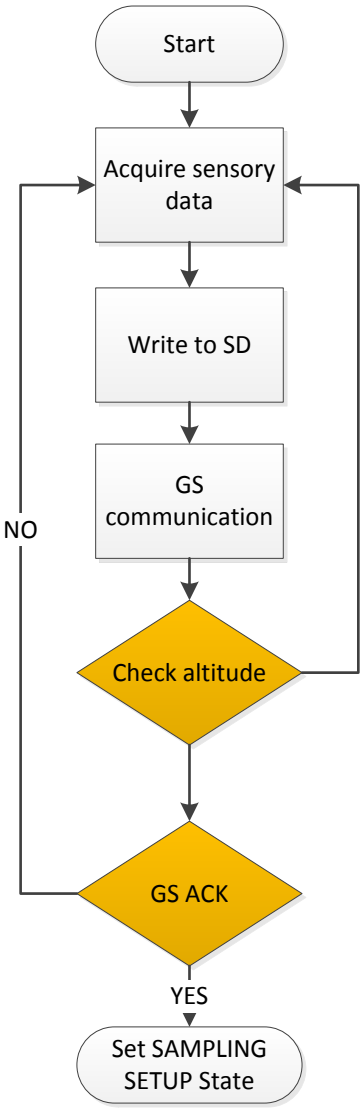


Figure 4.8-3 Climb state

Sampling setup

Enter condition: Experiment nominal altitude is reached

Exit condition: Valves are open

Operating Mode: Autonomous

Description: Before performing the sampling we have to open valves. In this stage a loop is used to open valves and check the flow inside the SU pipelines. All parameters are monitored, sent to GS, and logged on the internal SD.

System components	Status
Communication links	ON
Sensors	ON
Data-loggers	ON
Valves	OFF
Pump	ON
Air Ion Counters	ON
Particle Counter	ON
GPS	ON

Table 4.8-4 Sampling setup state

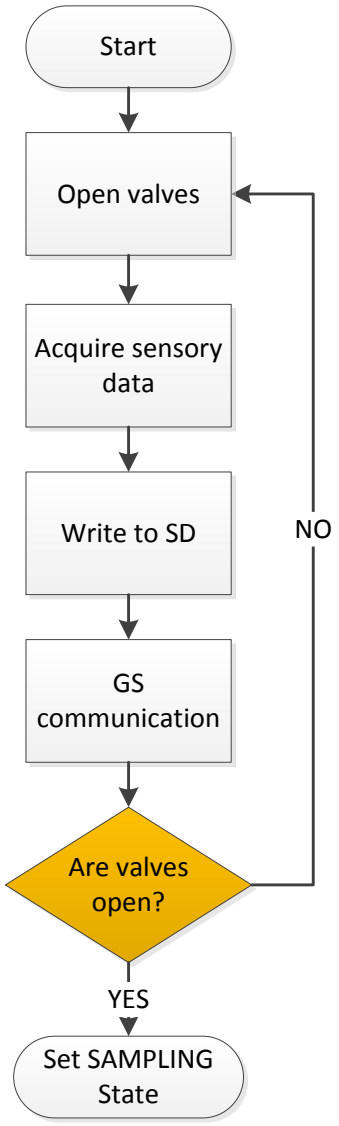


Figure 4.8-4 Sampling setup state

Sampling

Enter condition: Valves are open

Exit condition: GS request for experiment termination or experiment starts descending

Operating Mode: Autonomous/ GS-ACK

Description: Once the expected altitude is reached, the sampling shall begin. Valves are now open and air is flowing through SIOUTAS sampler. All parameters are monitored, sent to GS and logged on the internal SD. Some minutes before the cut off, a command is given by GS. Nonetheless also an autonomous function is implemented to close valves. Using GPS the descending rate is calculated. When it dramatically increases (descending speed higher than 5 m/s) an alert appears on GS interface and the operating mode is switched to GS-ACK. If acknowledgment is obtained or timeout occurs this stage is concluded and the system advances to the following step entering again in Autonomous Mode.

System components	Status
Communication links	ON
Sensors	ON
Data-loggers	ON
Valves	ON
Pump	ON
Air Ion Counters	ON
Particle Counter	ON
GPS	ON

Table 4.8-5 Sampling state

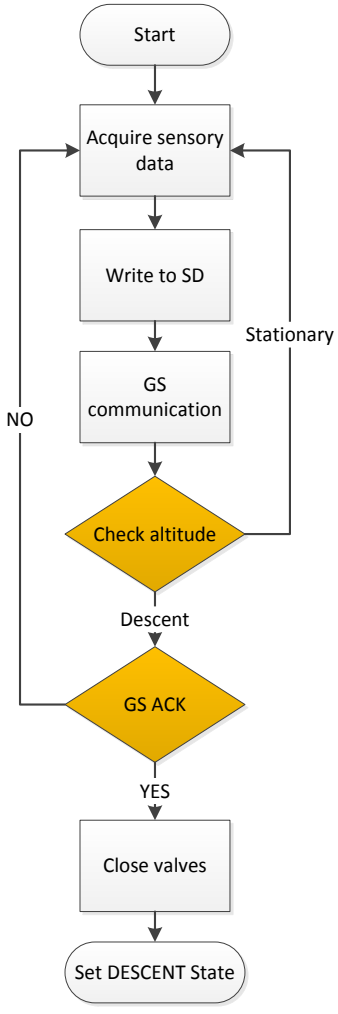


Figure 4.8-5 Sampling state

Descent

Enter condition: GS request or experiment starts descent

Exit condition: Experiment is turned off

Operating Mode: Manual / Autonomous

Description: Descent is the last stage of the mission. The SU line is closed and all the power lines are manually turned off one at a time using the current limiting switches. If no request is received from GS, after a certain timeout, the experiment switches to autonomous mode and turns off the power lines.

System components	Status
Communication links	ON
Sensors	ON
Data-loggers	ON
Valves	OFF
Pump	ON
Air Ion Counters	ON
Particle Counter	ON
GPS	ON

Table 4.8-6 Descent state

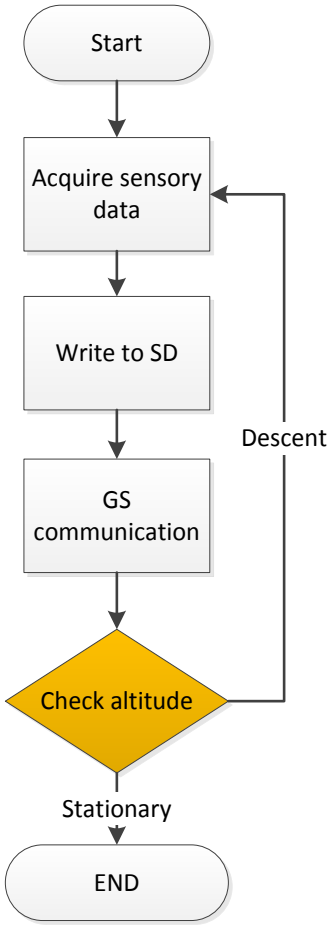


Figure 4.8-6 Descent state

4.8.5 Datagram structure

First of all we need to consider the header of the UDP itself that is 32 byte long.

A specific data protocol has been developed for A5-Unibo. Data packaging is different for the two sides of communication.

In the following the general datagram structure is shown.

CMD-ID	SN	CRC	DATA

Table 4.8-7 Datagram structure

Field	Description	Length	Description
CMD-ID	Command ID	1 byte	Command
SN	Serial Number	2 byte	Unique progressive serial number for CMD-ID (packet counter)
CRC	Checksum	2 byte	Check for data integrity
DATA	Data	depends on CMD-ID	Data bytes

Command (CMD-ID)
Define the structure of DATA field. CMD-ID assume value between 0 and 3.
Serial Number
This is a unique progressive number.
Data (DATA)
This field contains data bytes. The interpretation of all data bytes is message specific, i.e. depending on the CMD-ID value the meaning of bytes and the length of the field is different. The description of the specific message is in the following tables.
Checksum (CRC)
Checksum is obtained with a 2 byte cyclic redundancy check (16 bit CRC-CCITT[1]) to verify data integrity.

Structure of DATA

Table 4.8-8 UPLINK COMMAND datagram

CMD-ID=1	Description	Type	Description	Dimension [B]
MODIFY	Require changing	1 byte	Require changing	1
STATE	STATE value	1 byte	New value for STATE (1 to 6)	1
MODE	MODE value	1 byte	New value for MODE (1 to 3)	1
PUMP	PUMP value	1 byte	New value for PUMP threshold (0 to 255)	1

VALVES	VALVES value	1 byte	New value for VALVES (B00001111 open, B11110000 close)	1
TOTAL				**5**

CRC-CCITT with polynomial: $x^{16} + x^{12} + x^5 + 1$ (0x8408) and initial value: 0xffff (Arduino library <util/crc16.h>)

This field is filled with new values to set in OBDH. The MODIFY field is a bit that request modification of one or more of the values of STATE, MODE, PUMP or VALVES. In particular, its encoding is shown in the following.

bit 0	bit 1	bit 2	bit 3	bit 4	bit 5	bit 6	bit 7
STATE	MODE	PUMP	VALVES	CONFIRM	void	void	void

We should underline that this CMD-ID datagram is used also to acknowledge the request raised by OBDH. In fact bit 4 of MODIFY field is used as ACK

For instance if GS requires the change of both STATE and VALVES status, the resulting MODIFY byte will be:

10010000

CMD-ID=1 could be sent more than once, until the proper datagram of confirmation is received.

Table 4.8-9 DOWNLINK ACK datagram

CMD-ID=2	Description	Type	Dimension [B]
SN-ACK	Acknowledgment	2 byte	2
TOTAL			**2**

SN-ACK byte is used confirm the receiving of a CMD by replying the SN of the CMD received.

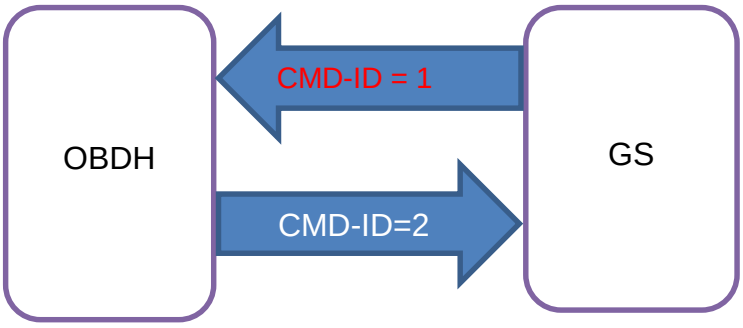


Table 4.8-10 DOWNLINK REQUEST CONFIRM datagram

CMD-ID=3	Description	Type	Dimension [B]
N-S	next STATE	1 byte	1
TOTAL			**1**

N-S is used to request confirm for changing to next STATE (e.g. CLIMB request when altitude starts increasing).

Table 4.8-11 UPLINK RESPONSE datagram

CMD-ID=4	Description	Type	Dimension [B]
N-S RESPONSE	next STATE response	1 byte	1
SN REF	reply serial number of req.	2 byte	2
TOTAL			**3**

This field is used to reply to a request for changing to next state.

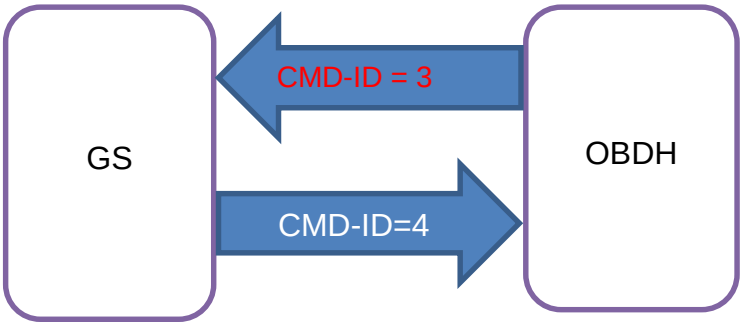


Table 4.8-12 DOWNLINK datagram

CMD-ID=5	Description	Type	Dimension [B]
LS	Time stamp (ms)	1 uint32_t	4
STATE	STATE	1 byte	1
MODE	MODE	1 byte	1
GPS_lat	GPS data	1 int32_t	4
GPS_lon		1 int32_t	4
GPS_alt		1 int16_t	2
Pressure	Pressure	1 uint16_t	2
AIC1	Air Ion Counter measure	1 uint16_t	2
AIC2	Air Ion Counter measure	1 uint16_t	2
OPC	LOAC measure	19 uint16_t	38

T	Temperature	1 uint16_t	2
RH	Relative humidity	1 uint16_t	2
FLAGS	Valves open	1 byte	1
	GPS status		
	OPC status		
	General status		
	Others (4bit TBD)		
	Others (8 bit TBD)	1 byte	1
TOTAL			**66**

In this case DATA is filled with all values measured by on-board software, plus some status flags. Moreover a Life Signal is used as incremental value, to have the number of cycles executed by on-board software. Both should be useful to evaluate the number of lost packages.

4.8.6 Total data rate

Finally we can provide an estimation of the total data rate required for data communication through E-link. Note that UDP header is due to UDP protocol itself and it is not handled by A5 Unibo software.

Table 4.8-13 shows the different packet's dimensions without any safety factor applied (data rate are the simple summation of all datagram fields).

Table 4.8-13 Total data-rate

CMD-ID	UDP header	Datagram header	DATA	CRC	Total	Period
1	32 byte	3 byte	5 byte	2 byte	42 byte (0.34 kbit)	o.r.
2			2 byte		39 byte (0.32 kbit)	o.r.
3			1 byte		38 byte (0.31 kbit)	o.r.
4			3 byte		40 byte (0.32 kbit)	o.r.
5			66 byte		103 byte (0.83 kbit)	10 sec

Minimum data rate:

0.83 kbit/s in DOWNLINK

Normal data rate:

0.83 kbit/s in DOWNLINK

Maximum data rate:

1.44kbit/s in DOWNLINK (0.83 kbit/s + 0.62 kbit/s on request) and 0.66 kbit/s in UPLINK (on request)

Applying a safety factor of 1.5, data rate would be:

Minimum data rate:

1.24 kbit/s in DOWNLINK

Normal data rate:

1.24 kbit/s in DOWNLINK

Maximum data rate:

2.16 kbit/s in DOWNLINK, 0.98 kbit/s in UPLINK (on request)

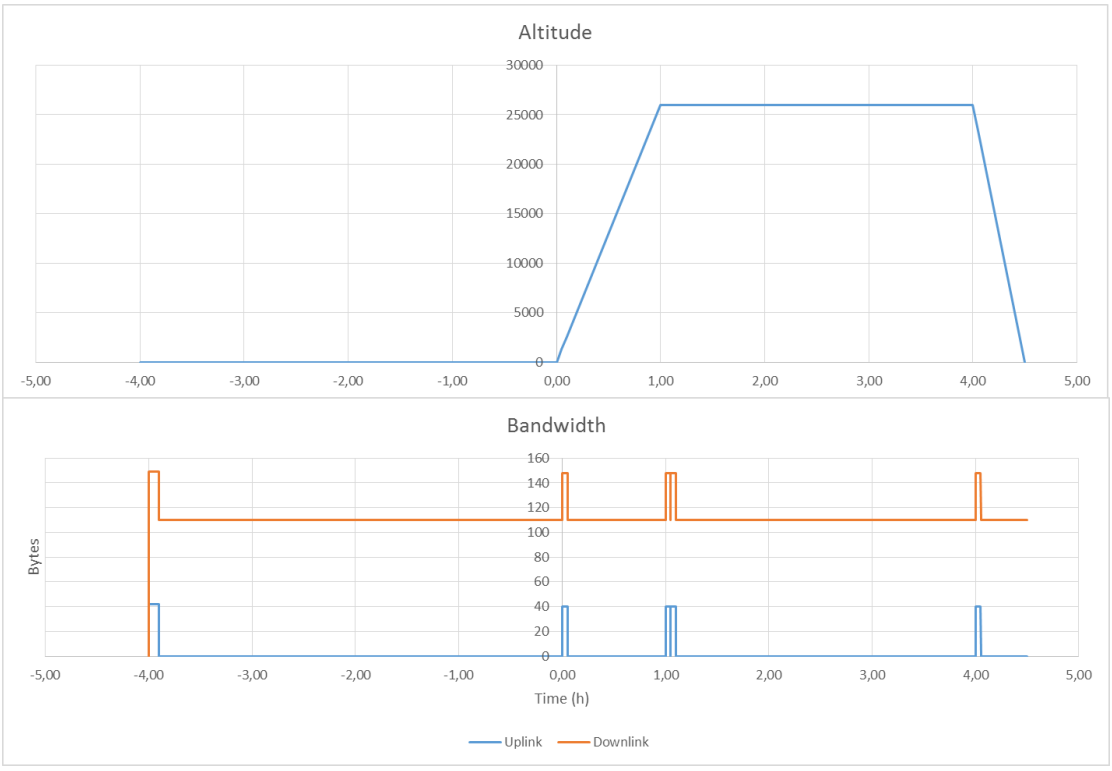


Figure 4.8-7 Bandwidth requirement related to altitude and mission time

Note that in figure 4.9-2, bandwidth is shown without any safety factor and assuming the ideal case in which GS command is requested only during Pre-Launch phase. The peaks in bandwidth correspond to altitude variation, when there is a request for change of SW state.

4.9 Ground Support Equipment

4.9.1 Ground Station Software

All data collected by the on-board unit has to be sent to the Ground Station and displayed via HID through a graphical interface. These data should include sensory data (i.e. ambient data, internal sensory, etc…) and they have to be eventually correlated with some flags reporting the status of the different components of the system. The interface in which these data are shown also allows the user to manually set some of the system parameters such as heaters, valves, pumps and specific instruments' on and off. GSS will be developed using LabVIEW.

Figure 4.9-1 GSS interface preliminary design

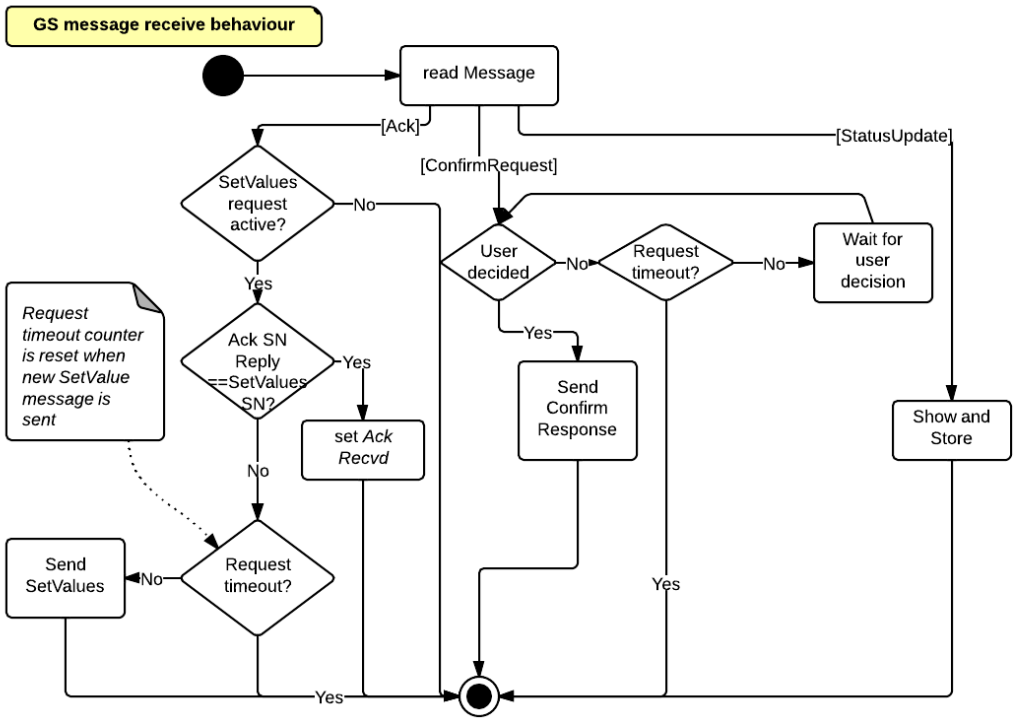


Figure 4.9-2 GS message receive behaviour

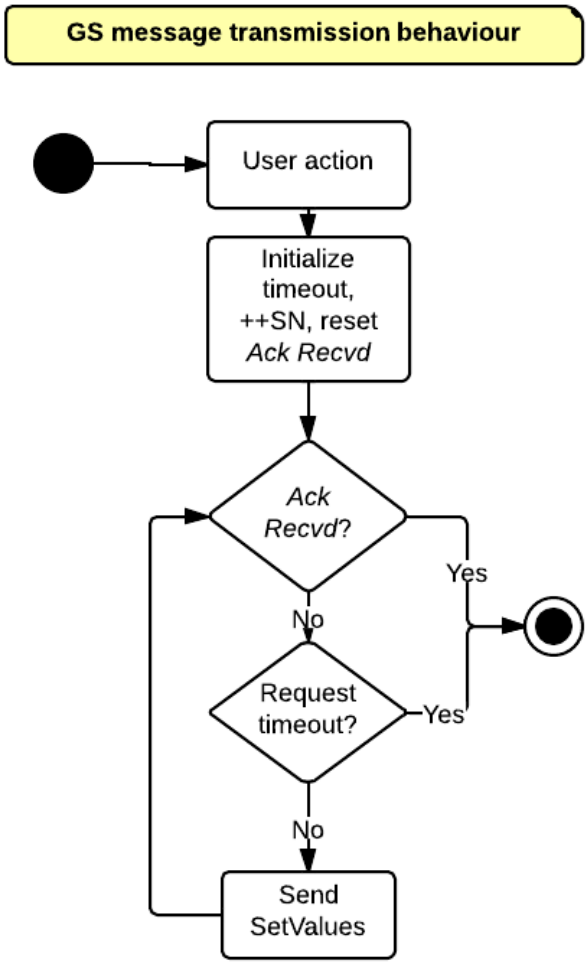


Figure 4.9-3 GS message transmission behaviour

4.9.2 GSS Communication Protocols

All data picked up by Arduino are correlated with some status flags and properly packaged. Finally, data packs are sent to GS using Ethernet shield to connect to E-Link (RJ 45 connector). A UDP connection is preferable for real time applications where a simple and fast communication is requested. UDP provides no handshake so it admits some data loss. This is not a real problem since critical data are stored inside an on-board memory card. Moreover we are not really interested to have any data that is not the most recent one, and above all we do not want to have long handshake time that could generate some problem involving timeout. To ensure a command has been received, we provide datagrams with two specific fields to identify a command, and to acknowledge if the command has been executed. A checksum provides the integrity of data datagram.

The UDP transmission is binary coded (Little-Endian data representation is used according to Arduino, since LabVIEW uses Big-Endian bytes are switched on GSS).

The design of the OBDH control logic is based on an architecture inspired by IEC 60848-SFC. The design team decided to adopt a simplified model due to the low complexity of the mission flow determined in problem analysis phase.

4.9.3 On Board Data Handling (OBDH)

Types of task:

- *Sporadic (S)*: executes once when activated. Sporadic tasks are pulsed after a state transition;
- *Periodic (P)*: executes several times according to a specified period. Periodic tasks can be stored, which means they keep on running even after the deactivation of their launching state, or non-stored, which means they keep running until their launching state remains active and reset when a state decides to shut them down.

Name	Typ	Period	Actions
enable_for_idle	S	NA	Communication links ON Sensors OFF Data-loggers OFF Valves OFF Pump ON Air Ion Counters OFF Particle Counter OFF GPS ON
enable_for_climb	S	NA	Communication links ON Sensors ON Data-loggers ON Valves OFF Pump ON Air Ion Counters ON Particle Counter ON GPS ON
enable_for_float	S	NA	• Communication links ON • Sensors ON Data-loggers ON • Valves ON • Pump ON Air Ion Counters ON

			• Particle Counter ON • GPS ON
enable_for_descent	S	NA	• Communication links ON • Sensors ON Data-loggers ON • Valves OFF • Pump ON Air Ion Counters ON • Particle Counter ON • GPS ON
sense_status_and_send	P	10 s	• Read all sensors Read all enabled instruments • Prepare status Save status to Data-Log • do *SendUpdate* interaction
poll_for_message	P	0.5 s	• Read UDP packet (if available) • Parse Message • In case of SetValues: set values and send Ack (*SendCmd* interaction*)* • In case of Ack: permit pending state change transitions (*AskForConfirm* interaction) by setting a Ack-Received-Flag
open_valves	P	0.5 s	• if valves are not open, open all valves.
close_valves	P	0.5	• if valves are open, close all valves.
start_pump	S	NA	• Start pump
stop_pump	S	NA	• Stop pump
check_systems	S	NA	• Active ALL sensors and instruments • Set *Manual Mode*
go_manual	S	NA	• Set *Manual Mode*
go_auto	S	NA	• Set *Automatic Mode*
ask_confirm_climb	P	0.5 s	• If *Increasing-Altitude Flag* is marked, do *AskForConfirm* interaction, set

			WaitingConfirm flag and initialize *WaitingConfirm time*. • If Increasing-Altitude Flag is marked and *WaitingConfirm* is set, update *Waiting-Confirm Time*. • If *Waiting-Confirm Time* is greater than *WaitLimit*, change state autonomously and reset flags.
ask_confirm_float	P	0.5 s	• If *StationaryAltitudeFlag* is marked, do *AskForConfirm* interaction, set *WaitingConfirm* flag and initialize *WaitingConfirmTime*. • If *StationaryAltitudeFlag* is marked and *WaitingConfirm* is set, update *WaitingConfirmTime*. • If *WaitingConfirmTime* is greater than *WaitLimit*, change state autonomously and reset flags.
ask_confirm_descent	P	0.5 s	• If *DecreasingAltitudeFlag* is marked, do *AskForConfirm* interaction, set WaitingConfirm flag and initialize *WaitingConfirmTime*. • If *IncreasingAltitudeFlag* is marked and *WaitingConfirm* is set, update *WaitingConfirmTime*. • If *WaitingConfirmTime* is greater than *WaitLimit*, change state

			autonomously and reset flags.
monitor_altitude	P	0.5 s	• Read pressure sensor • Determine when altitude is increasing and set *IncreasingAltitudeFlag*, *StationaryAltitudeFlag* or *DecreasingAltitudeFlag* • Set a flag *ExperimentAltitudeRange* when stabilized around 25000-30000 m. • Also set *GroundAltitudeRange* when stabilized around 0-2000 m.

States and transition

State	Enter Condition	Next States	Operations
Pre-launch	ε (initial)	NA (*)	**pulse** *check_systems* **store** *poll_for_message, sense_status_and_send*
Idle	ε	Climb	**pulse** *go_auto*, *enable_for_idle* **store** *monitor_altitude* **no-store** *ask_confirm_climb*
Climb	IncreasingAltitudeFlag, AckReceivedFlag	Sampling Init.	**pulse** *enable_for_climb*
Sampling Init.	StationaryAltitudeFlag && ExperimentAltitudeRange && AckReceivedFlag	Sampling	**no-store** *open_valves* **pulse** *enable_for_sample* **no-store** *ask_confirm_float*
Sampling	valves are open	Descent	**no-store** *ask_confirm_descent*
Descent	DecreasingAltitudeFlag && AckReceivedFlag	On Ground	**no-store** *close_valves*

On Ground	StationaryAltitudeFlag && GroundAltitudeRange	ε	*turn off*

NOTE:

(*) Pre-launch does not have a specific next state. The only way to exit this dead state is to manually specify the next state via proper command message (interaction SendCmd).

Manual Mode override

OBDH can also switch to manual mode if GS requires it. In this case all actuators are commanded exclusively via GS commands, and for this reason monitoring the E-Link connection becomes important.

Hardware Abstraction layer (HAL)

Following interfaces have been adopted in order to better separate HW dependent parts from the control logic of OBDH. This will meaningfully increase the testing capabilities of the software team. Further details at a5system/src/obdh_common/hal.h interface at code base.

4.9.4 Failure detection

A5-Unibo SW can detect and try to solve some possible errors. Possible failures that we can control are related to:

OBDH sensors' failure

A5-UNIBO uses several sensors with different communication protocols (I2C, SPI, UART and One Wire) so it is important to monitor the correct working of each process so that it does not compromise the whole system.

A *Watchdog timer* is used to detect if the execution flow is blocked in a certain task for an excessive amount of time, thus preventing the whole system to work. The execution could be blocked by a code error or a fault in hardware (e.g. an I2C sensor that never replies to a "send data" request). The task that has caused the whole system to stop is then disabled.

Communication with GS

E-Link communication is constantly monitored, especially when the OBDH in set in Manual Mode. When A5-Unibo is set in Manual Mode it acts according to

the instructions from GS, so in case of connection loss the OBDH can stall while waiting from a GS reply.

Manual Mode Override function is necessary to automatically switch OBDH to Autonomous Mode when E-Link connection is lost. In order to detect this communication loss, the GS periodically sends *heartbeat packets* when in Manual Mode. If the OBDH does not see a heartbeat packet for a long time, it switches back to Automatic Mode.

Critical Data transmission

A *Time Stamp* field is inserted at the end of critical data packet in order to associate data with the correct time.

For the OBDH we decided not to use hardware interrupts. The various tasks are scheduled to be executed in a single execution flow.

This choice has been done on the following reasons:

- Our system can work well and respect all timing constraints also without using interrupts;
- By not using interrupts we avoid the risk of failures caused by coding errors arising from the complexity of managing concurrency;
- All the tasks that are scheduled to run in the single execution flow, will be written in a way so that they are bound to end in a fixed maximum amount of time, so they cannot halt the system.

In this way we can be sure that the Ethernet receive buffer will never become full, because it will be regularly flushed by the OBDH. Moreover the Arduino platform and libraries we are using have been designed to work in a polling fashion, so using interrupts would require us to do a lot of difficult modifications in these already stable and well tested libraries.

Code Base

A Git repository “a5system” has been deployed at
https://bitbucket.org/a5unibo/a5system

5 EXPERIMENT VERIFICATION AND TESTING

Verification and Testing is a fundamental part of the experiment's development, and has the objective of assuring that every requirement (functional, performance, design and operational) is indeed fulfilled.

Every person is responsible for testing the subsystem and instruments they have been assigned to, but the whole team is responsible for the testing of the system during the integration process.

The following categories of verification processes have been used:

T – Verification by test

I – Verification by inspection

A – Verification by analysis or similarity

R – Verification by review of design

S – Similarity

Ref	Test has yet to be performed
Ref	Test has been performed with positive results
Ref	Test has been performed but will be repeated
Ref	Test has been performed with negative results
V	Requirement has been verified through the selected procedure

Table 4.9-1 Legend

5.1 Verification Matrix

Table 5.1-1 Verification matrix

Ref	Requirement	Test	Ver
FR1	The experiment shall measure particle size distribution outside the gondola during the whole flight.	OPCT1 OPCT2	R,T
FR2	The experiment shall measure particle ion densities outside the gondola during the whole flight.	AICT1 AICT2	R,T
FR3	The experiment should measure outside ambient temperature during the whole flight.	T4	R,T
FR4	The experiment shall measure outside ambient pressure during the whole flight	T9	R,T
FR5	The experiment should measure outside ambient relative humidity during the whole flight.		R,T

FR6	The experiment shall collect aerosol samples drawing air from outside the gondola during the floating phase in the stratosphere and make them available for post-flight analysis	PT1 PT2	R,T
FR7	The experiment shall keep track of its absolute position throughout the flight, in order to relate the collected data to a particular height and coordinate.	T8	R,T
FR8	The experiment shall measure the temperature inside the gondola in order to ensure the operational range of the instruments is not exceeded.	T3/T4	R,T
FR9	The experiment should measure the rate of air flow through the pump for the whole duration of sampling phase	*Not verified. Change in design*	R
FR10	The experiment shall record all the measured quantities into an internal SD	T8	R,T
FR11	The experiment shall relay to ground all the measured quantities	T8	R,T
PR1	Measurements for particles' size distribution shall be made at a rate of at least 1 measurement every 20 s, corresponding to a vertical resolution of 80-100 m, given the average ascending speed of 4-5 m/s	OPCT1	R,T
PR2	Measurements for ion densities shall be made at a rate of at least 1 measurement every 20 s, corresponding to a vertical resolution of 80-100 m, given the average ascending speed of 4-5 m/s	AICT1	R,T
PR3	The temperature measurements outside the balloon should be possible in a range between -90 and +30 °C	T4	R,T
PR4	The temperature measurements outside the balloon should be made with an accuracy of ±0.2 °C	*(data-sheet)*	I
PR5	The pressure measurements shall be possible in a range between 10 and 1100 mbar	T9	R,T
PR6	The pressure measurements shall be made with an accuracy of ± 1 mbar	*V (appendix)*	I
PR7	The humidity measurements should be possible in a range from 0% to 100% RH	*V (data-sheet)*	R,I
PR8	The humidity measurements should be made with an accuracy of ±2%	*V (data-sheet)*	I
PR9	The pump shall suck a nominal flow rate of 9 l/min at stratospheric conditions in order to maximize the efficiency of the collecting filter.	PT2	R,T

PR10	The altitude shall be measured with an accuracy of ±40 m	*(data-sheet)*	R,I
PR11	The coordinates shall be measured with an accuracy of ±40 m	*(data-sheet)*	R,I
PR12	The temperature measurements inside the gondola shall be possible in a range from -20º to 50º.	T3/T4	R,T
PR13	The temperature measurements inside the gondola shall have an accuracy of ±1 °C	*(data-sheet)*	I
DR1	The experiment shall withstand static vertical loads of 10 g and horizontal loads of ±5 g	Analysis	A
DR2	The experiment should withstand landing shocks of up to 35g.	T7	T
DR3	The experiment shall be able to operate while exposed to outside temperatures down to -15°C for the whole duration of pre-flight phase.	T3	R,T
DR4	The experiment shall be able to operate while exposed to outside temperatures down to -80°C for the duration of the flight.	T4	R,T
DR5	The experiment (and in particular the SD) shall withstand storage temperatures down to -15°C for the duration of the recovery procedures (up to 48 hours)	T3	R,T
DR6	Integrity of samples shall be guaranteed in case of water landing	T5	R,T
DR7	On the outside of the experiment housing, two 4 pin connector type MIL-C-26482P series 1 connectors shall be installed in order to access the gondola's power bus	*V*	R,I
DR8	The experiment batteries shall be qualified for use on a BEXUS balloon	T1	T
DR9	The experiment batteries shall either be rechargeable or shall have sufficient capacity to run the experiment during pre-flight tests, flight preparation and flight.	T8 Analysis	A,T
DR10	The batteries in the gondola-mounted experiment should be accessible from the outside within 1 minute	T8	R,T
DR11	The experiment housing shall be supplied with a sufficient number of brackets or a bottom rail plate to facilitate safe mounting of the experiment.	*V*	R
DR12	The experiment housing shall have mounting provision to interface on to M-EGON gondola	*V*	R

DR13	A panel mounted connector for the E-Link of the type Amphenol RJF21B must be used	V	R
DR15	Components that can represent a possible hazard for the recovery team (OPC's laser and batteries) shall be marked with a specific danger sign. (more details given in chapter 6)		I
DR16	All components used for the collection of aerosol samples shall be clean to ensure that particles collected are stratospheric rather than contamination		R,I
DR17	The pore size of the aerosols' collecting filters shall be 0.5 μm, to ensure collection of small particles	V	R
DR18	A sealing barrier shall be used to ensure that the components used for the collection of aerosol samples remains clean during assembly, testing and integration	V	R
DR19	A blank control sampling filter shall be added, identical to the sample holder, to monitor the environment during pre-launch, launch and flight and assess any possible contamination	V	R,I
SR1	SW shall be compatible with HW	ST1	R,T
SR2	SW shall not crash in case of error/Handle failure		R
SR3	SW shall monitor running time of each loop and eventually interrupt it (avoid delays in running time)	V	R
SR4	SW shall restart in case of failure (not be compromised in case of power loss)	ST1	R,T
SR5	SW shall not be locked in manual mode in case of data link loss	ST1	R,T
SR6	SW shall continue to work correctly in case of failure of some devices	ST1	R,T
SR7	SW shall correctly store all collected data	ST1	R,T
SR8	SW shall not overwrite or corrupt stored data		R
SR9	SW shall be redundant in the determination of descending phase start, meanly rely both on GPS and pressure data to determine descending rate but also request GS ACK	ST2	R,T
SR10	SW shall comply with E-Link and TCP/IP specification	ST1	R,T
SR11	SW shall not fail in case of GS connection failure and manage to reconnect	ST1	R,T
SR12	SW shall not to be crashed by GS commands error	ST1	R,T

SR13	GSS shall receive, display and log data	GST2	R,T
SR14	GSS shall allow user to set commands to on-board software	GST2	R,T
OR1	The experiment shall be able to function autonomously in the event that contact with Ground is lost.	T8	R,T
OR2	Piping materials and parts of the instruments coming out of the experiment shall be protected with a *remove before flight* cover		I
OR3	*Remove before flight cover* shall be removed before flight		I
OR4	The experiment shall autonomously open the pinch valves and unseal the sampling filter once reached the nominal altitude in the stratosphere.	T8	R,T
OR5	The experiment shall autonomously close the pinch valves and re-seal the sampling filter prior to the descent	T8	R,T
OR7	The experiment shall be turned off prior to entering the descending phase (Pump, AIC's and OPC should be disabled)	*V*	R
OR8	The amount of Offset for the AIC's shall be measured prior to the flight and it shall not be higher than ± 100 mV	AICT2	R,T

5.2 Test Plan

The following tables show a summary of all the main scheduled test and their procedures. Detailed procedures and results can be found in the BEXUS repository at: https://rexusbexus.zarm.uni-bremen.de/share/page/repository in the TEST folder for our experiment.

5.2.1 Pump Tests (PT)

Test number	PT1
Test type	Pump performance at ground conditions
Test facility	Flight Mechanics laboratory, University of Bologna
Tested item	Pump
Test procedure	Pump is turned on and its performance is evaluated at different DC voltage levels to verify if a linear correlation between voltage and flow exists. Volumetric flow is evaluating in two different ways:

	Measuring the time required to complete the inflation of a known fixed volume inflatable bag, and measuring a differential pressure through a Pitot tube. The first method is not so accurate and will be used only to assess the validity of the latter (PT2). Also a hot wire anemometer is employed for the calibration of the Pitot tube.
Test date	30/06/14
Completed	YES
Results	An active control of the airflow is successfully achieved using the MMmc, and both the methods have proven to be reliable for flow determination. In the first part (bag inflation), the 9 l/min flow was estimated to occur at approximately 2.5 V (corresponding to a duty cycle value of 250), while in the second (hot wire anemometer) at 2.6 V.

Test number	PT2
Test type	Pump performance at stratospheric conditions
Test facility	Flight Mechanics laboratory, University of Bologna
Tested item	Pump
Test procedure	Pump is put inside a vacuum chamber and ambient pressure reduced down to 10 mbar. Pump performance is evaluated using a Pitot tube and voltage level is set in so that the flow is exactly 9 l/m as requested to optimise samples' collection. The experiment is repeated at several ambient pressures ranging from 10 to 200 mbar and in the end a performance (external pressure/voltage for required flow) curve is obtained by fitting the results.
Test date	21/07/14
Completed	YES
Result	TBD

Test number	PT3
Test type	Pump vibration (micro-vibration)
Test facility	Alma-Space facilities
Tested item	Pump
Test procedure	The Pump is turned on and the voltage is set to the expected value that will be used at stratospheric conditions (depending on PT2 results). Vibrations at several operating voltages close to the selected value are evaluated using a vibration generating plate.

Test date	July
Completed	NO
Results	TBD

5.2.2 OPC performance tests

Test number	OPCT1
Test type	OPC performance at ground conditions
Test facility	Flight Mechanics laboratory, University of Bologna
Tested item	Optical Particle Counter
Test procedure	The OPC is turned on and output values for particle densities are compared with another (already used) instrument. Internal sensors' performance (flow, temperature, RH) is checked and average flow rate evaluated.
Test date	14/02/14
Completed	YES
Results	Output values obtained are consistent with the expected ones. Temperature, RH and flow sensors are functional. The nominal flow rate is measured by the internal sensor to be of 1 l/m (3 l/m considering air sheet for optics' cleanliness)

Test number	OPCT2
Test type	OPC performance in near-vacuum conditions
Test facility	Flight Mechanics laboratory, University of Bologna
Tested item	Optical Particle Counter
Test procedure	The OPC is put into a vacuum chamber, output values for particle densities, flow rate, and RH are recorded in micro-pressure conditions. Internal pump performance is evaluated using the internal flow sensor by operating the pump at several ambient pressures (ranging from 900 to 5 mbar). Pressure is decreased until a specific alarm code is read in the output, meaning that internal rotary vane pump has reached its maximum power but is not able to maintain the nominal flow of 1 l/m. Collected data is evaluated and should be consistent with values obtained in ambient pressure.
Test date	20/03/14
Completed	YES

Results	Test has shown that down to 500 mbar the internal pump is able to compensate for pressure drop and maintain an airflow of 1 l/m but as we go down to 400 mbar this threshold level cannot be reached anymore and the alarm code appears (meaning that pump is at its maximum but flow is not achieved). From this point onwards collected data cannot be considered reliable. Since these pressure levels are way higher than the ones we expect to encounter at floating phase we decided to use a different OPC. As soon as the new instrument is delivered a new series of test is going to be performed.

5.2.3 Air Ion Counter tests (AICT)

Test number	AICT1
Test type	AIC performance at ground conditions
Test facility	Flight Mechanics laboratory, University of Bologna
Tested item	Air Ion counter
Test procedure	AIC's are turned on and output values are evaluated and should be in agreement with the reference values from literature. Data acquisition through ADC and SD are checked. The Offset value is evaluated by turning off the fan while AIC's are still on and its value should be below ±100 mV.
Test date	17/04/14
Completed	YES
Results	Data is successfully acquired and is in agreement with reference values. Offset values are measured to be around -2 mV for the positive unit and -8 mV for the negative one.

Test number	AICT2
Test type	AIC performance at stratospheric conditions
Test facility	Flight Mechanics laboratory, University of Bologna
Tested item	Air Ion counter
Test procedure	The AIC is put into a vacuum chamber and turned on. Output values for ion densities are recorded and evaluated at several ambient pressures ranging from 1000 to 5 mbar. Offset is then measured at several ambient pressures to see if a relationship between offset and pressure exists.
Test date	06/05/14

Completed	YES
Results	Both the AICs work properly in a low pressure environment. Offset is found to be independent from pressure levels.

Test number	AICT3
Test type	AIC performance at stratospheric conditions
Test facility	Flight Mechanics laboratory, University of Bologna
Tested item	Air Ion counter
Test procedure	Offset values are measured at several ambient temperatures ranging from 0° C to -70° C (depending on the facility) to create a Temperature/Offset profile
Test date	July
Completed	NO
Results	TBD

5.2.4 Software Tests (ST)

Test number	GST1
Test type	Transmission/Ground station
Test facility	University of Bologna
Tested item	ECU (Arduino + Ethernet shield), GS
Test procedure	Arduino is connected to PC via bridge using an Ethernet 10/100 cable. IP and subnet mask are set as specified in E-link user's manual. • Arduino and LabVIEW compatibility with IP range is checked. • Data exchange is performed between Arduino and PC by using LabVIEW to check various types of data. • A first attempt to check connection stability is performed.
Completed	YES
Results	Test successfully completed. Some improvements to be performed in GST2

Test number	GST2
Test type	Transmission/Ground station
Test facility	University of Bologna

Tested item	ECU (Arduino + Ethernet shield), GS
Test procedure	Arduino is connected to PC via bridge using an Ethernet 10/100 cable. IP and subnet mask are set as specified in E-link user's manual. • A deeper connection stability test is successfully performed. • Best timing delays to have a good transmission are evaluated. • Forcing conditions to crash the GS VI are investigated.
Completed	YES
Results	Test successfully completed. Other improvements to be implemented in GST3

Test number	GST3
Test type	Transmission/Ground station
Test facility	University of Bologna
Tested item	ECU (Arduino + Ethernet shield), GS
Test procedure	Arduino is connected to PC via bridge using an Ethernet 10/100 cable. IP and subnet mask are set as specified in E-link user's manual. • Connection stability is tested, also by physically forcing it. • Performance in terms of data rate and PC memory usage are investigated. • CRC algorithm is checked on both sides.
Test duration	5 hours
Completed	NO
Results	TBD

Test number	ST1
Test type	Software performance
Test facility	University of Bologna
Tested item	ECU, instruments, GS
Test procedure	ECU is assembled and connected to the scientific instruments (OPC, AIC's, pressure sensor, temperature sensors, humidity sensor, and GPS) and to GS via e-link connection. All instruments and ECU are turned on and correct acquisition of data is checked, both on SD and through data logging to GS.

	A series of operations is then performed to verify that main SR are fulfilled: 1. Power is manually switched off and of by unplugging and re-inserting the power cable (SR4). 2. Request for manual mode is sent and then connection is removed (SR5) 3. All the instruments are turned off one at a time and then turned on again while experiment is running (SR6) 4. Connection to GS is interrupted by unplugging the e-link cable, and reconnected later on (SR11) 5. Unknown or wrong commands are sent from GS (SR12)
Test date	June
Completed	NO
Results	TBD

Test number	ST2
Test type	Operating Simulation (flight sequence)
Test facility	University of Bologna
Tested item	ECU, Instruments, GS
Test procedure	A complete flight sequence is performed giving false GPS signals in order to switch between the different software modes. Moreover GS commands are going to be sent in order to evaluate manual override. A second flight sequence is performed, where loss of contact with GS is simulated by unplugging the e-link cable to evaluate the capability of the system to autonomously perform the flight sequence.
Test date	August
Completed	NO

5.2.5 General Tests (T)

Test number	T1
Test type	Vacuum
Test facility	Flight Mechanics Lab. University of Bologna

Tested item	Integrated system
Test procedure	The whole experiment will be integrated and put into a vacuum chamber (pressure at 0.01 mbar). Pre-flight checks and flight sequence will be performed during the lowering of the pressure and once reached vacuum. Experiment temperature will be constantly monitored and recorded using several sensors.
Test date	August
Completed	NO
Results	TBD

Test number	T2
Test type	Vibration
Test facility	University of Bologna
Tested item	Integrated system
Test procedure	Pump and instruments are turned on to evaluate functionality of electronics and sensors and structural integrity under vibrational environment.
Test date	August
Completed	NO
Results	TBD

Test number	T3
Test type	Thermal (pre-launch phase simulation)
Test facility	TBD
Tested item	Integrated system
Test procedure	The whole experiment will be integrated and put into a thermal chamber (or refrigerator) for at least 2 hours Temperature will be set to -15 C (expected temperature during pre-launch phase). Pre-flight checks and sequences are going to be performed while temperature will be constantly monitored and recorded using several sensors
Test date	August
Completed	NO
Results	TBD

Test number	T4
Test type	Thermal
Test facility	TBD
Tested item	Integrated system
Test procedure	The integrated experiment will be put into a thermal chamber with its temperature set to -40 C, or even to a lower one, depending on the performance of the facility (ideally -80 C). The experiment will then be turned on and flight sequence will be performed for the whole duration of flight plus an extra of 15 minutes. Temperatures will be monitored and recorded in different critical points of the experiment. Also functionality of the instruments will be checked by analysing the gathered data
Test date	August
Completed	NO
Result	TBD

Test number	T5
Test type	Water Landing
Test facility	University of Bologna
Tested item	Tubing with sealing valves
Test procedure	Sealed tube containing an absorbing material is submerged in water for 1 day. The material is inspected to see if the sealing valves have worked properly.
Test date	July
Completed	NO
Results	TBD

Test number	T6
Test type	Random Vibration
Test facility	Alma Space facilities
Tested item	Mechanical structure
Test procedure	Structure is filled with a dummy load and put on a plate at the Alma-Space facilities that is able to generate random vibrations. Structure integrity is checked afterwards by visual inspection.
Test date	July

Completed	NO
Results	TBD

Test number	T7
Test type	Drop Test
Test facility	University of Bologna
Tested item	Mechanical structure
Test procedure	Structure is filled with a dummy load and dropped from 3 metres height. Structural integrity is checked by visual inspection while the load factor is measured using an accelerometer.
Test date	July
Completed	NO

Test number	T8
Test type	Flight simulation
Test facility	University of Bologna
Tested item	Integrated system
Test procedure	A complete flight sequence (including pre-launch checks) is performed giving false GPS signals in order to switch between the different states. Data is collected onto the internal SD and sent to ground station through e-link to allow for an evaluation of the instruments performance. The experiment is run for the whole time duration to verify batteries' performance.
Test date	August
Completed	NO
Results	TBD

Test number	T9
Test type	Pressure sensor test
Test facility	University of Bologna
Tested item	Pressure sensor and ECU
Test procedure	The pressure sensor is mounted on the ECU and put into a vacuum chamber. ECU is turned on and barometric measurements are recorded while the ambient pressure is reduced down to 5 mbar. Desired operational range has to be reached.
Test date	07/07/14
Completed	YES
Results	Pressure sensor's desired operational range is reached

Test number	T10
Test type	Sensors' acquisition
Test facility	Flight Mechanics laboratory
Tested item	All the sensors: Temperature, Humidity, Pressure, GPS, OPC and AIC's.
Test procedure	After the correct working of each single sensor has been tested, the sensors are connected all together to Arduino to check for any incompatibility in the communication protocols (SPI, I2C, UART and Serial). Hardware failure is simulated by physically disconnecting one device at a time, without changing the operating software.
Test date	July
Completed	NO
Result	TBD

5.3 Test Results

Detailed procedures and results for each test can be found at the REXUS/BEXUS repository at https://rexusbexus.zarm.uni-bremen.de/share/page/repository in the TEST folder for our experiment.

6 LAUNCH CAMPAIGN PREPARATION

6.1 Input for the Campaign / Flight Requirement Plans

6.1.1 Dimensions and Mass

Experiment mass (in kg):	9 kg
Experiment dimensions (in m):	450mm*445mm*412mm
Experiment footprint area (in m^2):	0.20 m^2
Experiment volume (in m^3):	0.08 m^3
Experiment expected COG (centre of gravity) position:	300mm x axis 270mm y axis 210mm z axis

6.1.2 Safety Risks

Risk	**Mitigation / precaution measures**
OPC's laser	OPC contains a class 3B laser diode (635 nm, 25 mW) whose light beam is totally confined under normal operation. If this is the case it is graded as a Class 1 Laser product and is of no hazard to the user. Anyway it will be marked with the following warning sign.
Batteries	MP 176065 Integration SAFT batteries are reliable, but risks related to common batteries still exist, and in particular explosion due to over-exploitation. The following mitigating solutions are implemented: • Detailed power budget calculations and tests are performed • Current limiting switches are inserted to avoid pulse discharges and overconsumption. • Battery packs are kept in a separate closed box (BHA) covered with aluminium plates and labelled with a warning sign
Pump	Pump may overheat due to friction and low dissipation at stratospheric conditions. Detailed testing will show whether cooling has to be done. Pump is turned off before descent to keep the working time as low as possible and to avoid the suction of debris or water after the landing that could cause damage to the pump itself.

External elements	Piping material (inlet and outlet ports of the SU) and TSP inlet of the OPC are coming out of the Gondola and could be accidentally hit while moving the experiment. A clearly visible RBF cover is added to identify these two elements.

6.1.3 Electrical Interfaces

Table 6.1-1 Electrical interfaces applicable to BEXUS

BEXUS Electrical Interfaces		
E-Link Interface: E-Link required? Yes		
	Number of E-Link interfaces:	1
	Data rate - downlink:	2.16* kbit/s
	Data rate – uplink	0.98* kbit/s
	Interface type (RS-232, Ethernet):	Ethernet
Power system: Gondola power required? Yes		
	Peak power (or current) consumption:	29.41 W
	Average power (or current) consumption:	29.41 W **
Power system: Experiment includes batteries? Yes		
	Type of batteries:	Lithium Ion
	Number of batteries:	12
	Capacity (1 battery):	6.8 Ah
	Voltage (1 battery):	3.75 V

*A safety factor of 1.5 has been applied.

** Average and peak power are the same cause we estimated power on for 7 hours (flight duration without descending phase)

6.2 Preparation and Test Activities at Esrange

6.2.1 Launch site requirements

At Esrange Space Centre we will need the following:

- Mechanical tools.
- Electrical tools.
- Regulated DC power supply with output up to 28V and 6A. Two separate output lines will be needed during the tests to simulate PL1 and PL2
- Compressed air blower for AIC's cleaning.
- A cleaned room where to assemble the SU and install the Sioutas

Sampler once delivered at Esrange.

In addition to these we will also bring with us the following items, necessary for the sampling unit preparation:

- Analyslide Petri Dishes
- Cleaning solution (isopropyl alcohol)
- Stainless steel forceps
- Particle free gloves
- Ultrasonic bath to clean the pipes and all the components exposed to the airflow

6.2.2 Flight requirements

We have no strict requirement about the flight, however as explained in section 4.3-4 a flight duration of at least 3 or 4 hours would increase the chance of a meaningful particle detection. Moreover, to reduce the amount of heating to be given by the foil heaters, a daytime flight is preferable, due to the presence of higher temperatures and of solar radiation.

6.2.3 Preparation of the SU

The Sioutas sampler will be prepared and mounted (with the instalment of the filters) at our facilities at the University of Bologna; then the whole unit will be shipped to Esrange where it will be installed inside the Sampling Unit.

This choice has been made based on the following reasons:

- A clean room of at least class 1000 (or 100 if available) is necessary in order to safely install the filters without the risk of contamination, and this facility is currently unavailable at Esrange.
- Preparation and mounting procedures take a long time. The total preparation time is estimated to be around 10 hours (1 hour for demounting, 6 hours for cleaning, 2 hours of filter weighing and 1 hour of mounting) and other 24 hours are required for filters' conditioning.
- Instrumentation needed for conditioning and weighing of the filters is fragile and expensive, and therefore shipping could be dangerous.

More details about filter preparation can be found in appendix.

In the following table, a list of the activities to be performed at Esrange is provided. Note that some timing should be adjusted later on during the project development, since these are just estimations.

Duration	What	Who
Day 1		
1 h	Preparation of the cleaned room	Erika, Elisa
30 min	Unpacking of the Sioutas Sampler	Erika, Elisa
1 hour	Cleaning of critical components (tubes, pipes, and inlets) using ultrasonic bath	Erika, Elisa
1 hour	Cleaning of non-critical components (box, valves and mounting provisions) with cleaning solution	Erika, Elisa
2 hours	Mounting of the Sampling Unit	Riccardo, Erika, Elisa
Day 2		
1 hour	Instalment of the SU in the experiment	Riccardo, Paolo
	Placement of the RBF seal	Riccardo, Paolo

6.3 Timeline for Countdown and Flight

A5 Unibo will take part of **BEXUS-18** launch in October 2014.

Table 6.3-1 Pre-flight operations

Pre-flight status
Connect external power supply
Main power ON
Visual check of structure integrity
Visual check of accessible electronics, battery and probes
Check battery charge

Table 6.3-2 Flight sequence

Flight sequence		
Time	Operation	Who
T-5H	Decision meeting	EuroLaunch

T-4H30	ECU preparation with E-Link remote access (physical Ethernet connection) [20-30min] Remove all RBF objects BUT the SU inlet **WARNING**: Removing SU inlet protection would expose the SIOUTAS to direct flow when checking valves. If removed immediately reinsert it. Perform structure visual inspection [15 min] **Switch on the ECU** Perform hardware checklist [30 min] Start Pre-launch test by GS: [10 min max] 1. Turn on valves 2. Turn off valves 3. Start OPC data acquisition 4. Start AIC+ data acquisition 5. Check AIC+ offset switch 6. Start AIC- data acquisition 7. Check AIC- offset switch 8. Switch on Pump 9. Check control by ESC Motion Mind 10. Switch off Pump 11. Start Pressure sensor acquisition 12. Start Humidity sensor acquisition 13. Start Temperature sensor acquisition 14. Start GPS data acquisition Check battery charge, if necessary substitute. [<5min] Set SW IDLE state if checklist is verified	A5-Unibo team
T-3H30	Declare READY FOR LAUNCH	Nani
T-2H30	Payload moved from Cathedral. NO MORE PHYSICAL ACCESS TO GONDOLA	EuroLaunch
T-1H45	Payload to launch position.	EuroLaunch
T-1H30	Decision meeting Balloon Operations	EuroLaunch
T-1H	**Switch on pump by GS request** Start offset measurements the two AICs	Igor
T-0H55	**Remove all RBF objects and tags**	EuroLaunch

T-0H45	Access to gondola pad ends.	
T-0H35	Starts balloon inflation.	EuroLaunch
T-0H30	Final pre-flight operation Check software state and confirm IDLE state	Igor, Nani
T-0H10	Lift gondola **GS ACK for CLIMB state**	EuroLaunch GS operator
T0	Balloon released.	EuroLaunch
T2H00	Balloon reaches sampling altitude	
	GS ACK for sampling altitude	GS operator
	Set SW SAMPLING INIT (valves open)	
	Set SW SAMPLING	
	REQUIREMENT: Need few minutes (5-10 minutes) pre-warning from EuroLaunch of balloon cut-down Checklist: • ECU SW manually set to DESCENT • Turn OFF pump • CLOSE valves • Close PL1 • Close PL2 • Turn off the experiment	GS operator
T5H00	**Balloon cut-down**	EuroLaunch
T5H45	Balloon lands	

6.4 Post-Flight Activities

Post-Flight activities include detailed data and sample analysis that will be further described in section 7, as well as an evaluation of the flight sequence and of the integrity of instruments and experiment structure.

6.5 System Success

Subsystem	Level of Success
Optical Particle Counter	

The OPC should measure particles' size distributions at a rate of one measurement every 20 s up to an altitude of at least 10 Km	20%
The OPC should measure particles' size distributions at a rate of one measurement every 10 s up to the maximum altitude reached during the flight	50 %
Air Ion Counters	
The AIC's should measure the ion densities at a rate of one measurement every 20s up to an altitude of at least 10 Km	10%
The AIC's should measure the ion densities at a rate of one measurement every 10s up to the maximum altitude reached during the flight.	30%
Aerosols' Sampling	
The SU should collect enough particles to allow for SEM analysis, and it should guarantee that particles are stratospheric rather than tropospheric.	10 %
The SU should collect enough particles to allow for SEM and PIXE analysis, and γ-Ray spectrometry. Moreover it should guarantee that particles are stratospheric rather than tropospheric and sort the samples by their size between the different filters.	20%

7 DATA ANALYSIS AND RESULTS

7.1 Data Analysis Plan

7.1.1 Atmospheric data analysis

What we expect to gather during the flight is a continuous set of values for ambient parameters (such as Temperature, Pressure and RH) and for Ion and Particulate densities, each one of them related to a specific height and time.

Acquired data will be processed for obtaining mono-variant and multi-variant statistical analysis: descriptive statistics, correlation analysis, time series analysis and other multivariate statistical techniques (such as cluster and factor analysis, for instance) will be performed on the acquired data matrix. The results will be obtained by means of some commercial software, such as Microsoft Excel, Statistica, OriginLab, as well as by means of some freely available R packages and MATLAB codes.

7.1.2 Sample analysis

After recollection of the experiment, the samples will be extracted in a safe way, and transported to our facilities at the University of Bologna, where the following analyses are going to be performed:

SEM

The Scanning Electron Microscopy (SEM) is a method for high-resolution imaging of surfaces. The SEM uses electrons for imaging, as well as light microscope uses visible light. The SEM generates a beam of incident electrons in an electron column above the sample chamber. The electrons are produced by a thermal emission source, such as heated tungsten filament, or by a field emission cathode. The energy of the incident electrons can be as low as 100 eV or as high as 30 keV depending on the evaluation objectives. The electrons are focused into a small beam by a series of electromagnetic lenses in the SEM column and directed towards the sample. The incident electrons cause electrons to be emitted from the sample due to elastic and inelastic scattering events within the sample's surface and near-surface material. High-energy electrons that are ejected by an elastic collision of an incident electron, typically with a sample atom's nucleus, are referred to as backscattered electrons. The energy of backscattered electrons will be comparable to that of the incident electrons. Emitted lower-energy electrons resulting from inelastic scattering are called secondary electrons. Secondary electrons can be formed by collisions with the nucleus where substantial energy loss occurs or by the ejection of loosely bound electrons from the sample atoms. The energy of secondary electrons is typically 50 eV or less. To create an SEM image, the incident electron beam is scanned in a raster pattern across the sample's surface. The emitted electrons are detected for each position in the scanned area by an electron detector. The intensity of the emitted electron signal is displayed as

brightness on a cathode ray tube (CRT). By synchronizing the CRT scan to that of the scan of the incident electron beam, the CRT display represents the morphology of the sample surface area scanned by the beam. Magnification of the CRT image is the ratio of the image display size to the sample area scanned by the electron beam. The SEM uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interactions reveal information about the sample including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample. The SEM is also capable of performing analyses of selected point locations on the sample; this approach is especially useful in qualitatively or semi-quantitative determining chemical composition (using Energy-Dispersive detectors), crystalline structure, and crystal orientations (using Electron Backscatter Diffraction detectors).

The SEM/EDS laboratory at Biological, Environmental and Geological Sciences at the Bologna University is equipped with a SEM Philips 515 with a BS detector with high efficiency. It has a video card for digital acquisition of images IMAGESLAVE®. The instrument is an EDAX DX-4 for energy dispersive microanalysis and the apparatus for the preparation of samples is formed by a carbon coater and sputter coater.

Figure 7.1-1 SEM setup at BIGEA laboratory

PIXE

Particle Induced X-ray Emission or Proton Induced X-ray Emission (PIXE) is a powerful, yet not destructive, elemental analysis technique used in the determination of the elemental make-up of a material or sample. This technique involves the excitation of the atoms in the sample to produce characteristic X-ray and a means of detection. The X-ray spectrum is initiated by irradiating the

sample with a proton beam produced from pure Hydrogen by a Van der Graaf accelerator.

When a sample is irradiated with the proton beam, the protons interact with the electrons to create inner-shell vacancies in the atoms present in the sample material. The energies of the X-rays, which are emitted when these vacancies are filled again, are characteristic of the elements from which they originate. The number of X-rays of a certain energy is proportional to the mass of the corresponding element found in the sample. A Lithium drifted Silicon detector is used for data acquisition, allowing for the simultaneous analysis of the elements from Sodium through Uranium. Data reduction is then accomplished using computer software which normalizes the detected X-ray intensities against those measured from pure standards for each element. Thus, elements are easily identified and quantified.

University of Bologna has a long-term collaboration with the INFN National Laboratories of Legnaro (Padova). The PIXE set-up at INFN-Legnaro is the following one: Amplifier ORTEC 672, ADC Silena, Multichannel Ortec Match-Maker, Software Lab-View; Chamber with a steel cylinder Ø 20 cm, 5-10 automatic samples holder, turbo-molecular pump vacuum 10-6; the detector is a Ge Iper-pure Canberra with a surface area 100 mm^2, crystal thickness 1 cm, polymer window 0.4 µm, resolution 160 eV (137 eV measured), distance from the target 3 cm, detector-target angle 45°, beam-target angle 0°; funny filter Mylar 60 µm, hole 10%.

Figure 7.1-2 PIXE setup at INFN-Legnaro

Γ-Spectrometry

Germanium detectors are semiconductor diodes having a PIN structure in which the intrinsic (I) region is sensitive to ionizing radiation, particularly x-rays and gamma rays. Under reverse bias, an electric field extends across the intrinsic or depleted region. When protons interact with the material within the depleted volume of a detector, charge carriers (holes and electrons) are produced and are swept by the electric field to the P and N electrodes. This

charge, which is proportional to the energy deposited in the detector by the incoming photon, is converted into a voltage pulse by an integral charge sensitive preamplifier.

The germanium detector is cooled with liquid Nitrogen in order to reduce the thermal generation of charge carriers (thus reverse leakage current) and mounted in a vacuum chamber. The sensitive detector surfaces are thus protected from moisture and condensable contaminants.

Germanium detectors allow non-destructive measurements, i.e. no radiochemical separations are necessary and provide information about both the energy and rate of photons reaching the detector, i.e they provide a spectrum, where photons with different energy can be recorded simultaneously. The resolution of Germanium detectors is much better than other photon detectors such as scintillators, and this allows differentiating photons with quite similar energies.

In the Laboratory of Environmental Radiochemistry (LER), gamma spectrometry measurements are carried out using two low background Hyper Pure Germanium crystal detectors, a p-type coaxial and a planar, respectively for higher and lower energy ranges (50-2000 keV and 0-900 keV). The first one has a relative efficiency of 38% and FWHM of 1.8 keV at 1332 keV, while the second one has an active surface of 1500 mm^2 and FWHM of 0.73 keV at 122 keV. Spectra are processed with a specific software package GammaVision-32 (version 6.07, Ortec).

Figure 7.1-3 Germanium detectors at ERL

7.2 Launch Campaign

TBD

7.3 Results

TBD

7.4 Lessons Learned

Even though we are only in the preliminary phases of launch campaign some lessons have already been learnt during the PDR and CDR preparation phases:

- Deadlines are necessary for the group and the single members in order to be able to keep on track and follow the schedule.
- It is very important to have team meetings at least once a week and to work all together whenever possible. Problems that can take long time for a single person to be solved are often solved really quickly when the whole group gathers.
- Components have to be identified and ordered as quickly as possible, since communication with companies often requires a lot time and work (data-sheets unavailable, communication delays or misunderstandings).
- Conflicts can arise within the group and a lot of effort has to be put into building a strong team spirit and cohesion.
- Team members can become unavailable for some periods of time due to work or personal issues and backup solutions have to be arranged in time.

8 ABBREVIATIONS AND REFERENCES

8.1 Abbreviations

AIT	Assembly, Integration and Test
BD	Back-scatter Diffraction detector
BHA	Battery Housing Assembly
BJT	Bipolar Junction Transistor
CCN	Cloud Condensation Nucleus
CD	Cloud Droplet
CDR	Critical Design Review
CR	Cosmic Ray
CRP	Campaign Requirement Plan
CRT	Cathode Ray Tube
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EAT	Experiment Acceptance Test
EAR	Experiment Acceptance Review
ECU	Electronic Control Unit
EHA	Electronics Housing Assembly
EIT	Electrical Interface Test
EPM	Esrange Project Manager
ESA	European Space Agency
Esrange	Esrange Space Center
ESTEC	European Space Research and Technology Centre, ESA (NL)
ESW	Experiment Selection Workshop
FAR	Flight Acceptance Review
FST	Flight Simulation Test
FRP	Flight Requirement Plan
FRR	Flight Readiness Review
GS	Ground Station
GSS	Ground Station Software
GS-ACK	Ground Station Acknowledgment
GSE	Ground Support Equipment
HW	Hardware
HK	House Keeping
HID	Human Interface Device
ICD	Interface Control Document
IHA	Instruments Housing Assembly
IIN	Ion Induced Nucleation
IPR	Integration Progress Review

IR	Infra-Red
LT	Local Time
LOS	Line of sight
Mbps	Mega Bits per second
MFH	Mission Flight Handbook
MORABA	Mobile Raketen Basis (DLR, EuroLaunch)
OP	Oberpfaffenhofen, DLR Center
OPC	Optical Particle Counter
PCB	Printed Circuit Board (electronic card)
PDR	Preliminary Design Review
PIXE	Proton induced X-ray Emission
PST	Payload System Test
RBF	Remove Before Flight
SD	Storage Device
SED	Student Experiment Documentation
SEM	Scanning Electron Microscope
SFA	Support Frame Assembly
SNSB	Swedish National Space Board
SODS	Start Of Data Storage
STW	Student Training Week
SU	Sampling Unit
SW	Software
TBC	To be confirmed
TBD	To be determined
UL	Unsigned long
WBS	Work Breakdown Structure
ZARM	Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation

8.2 References

[1] **Climate Change 2007:** The Scientific Basis. Contribution of working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK

[2] Albrecht B.A,, **1989. Aerosols, cloud microphysics**, and fractional cloudiness. Science 245(4923), 1227–1230

[3] Svensmark H., Friis-Christensen E., **1997. Variation of cosmic ray flux and global cloud coverage** – a missing link in solar-climate relationship. J. Atmos. Solar Terr. Phys. 59(11), 1225-1232

[4] Carlslaw K.S., Harrison R.G., Kirby J., **2002. Cosmic Rays, Clouds, and Climate**. Science, 298 (5599), 1732-1737.

[5] Lee et al, 2003. Lower Stratosphere Particle Formation by Ion Nucleation in the Upper Troposphere and Lower Stratosphere. Science 301, 1886-1889

[6] Kirby J. et al., 2011. Role of sulphuric acid, ammonia and galactic cosmic rays in atmospheric aerosol nucleation. *Nature* 476(7361), 429-433.

[7] P. Palumbo, V. Della Corte, A. Rotundi, A. Ciucci, A. Aronica, J. R. Brucato, L. Colangeli, F. Esposito, E. Mazzotta Epifani, V. Mennella, R. Battaglia, G. Ferrini, F. J. M. Rietmeijer, G. J. Flynn, J. B. Renard, J. R. Stephens, E. Zona, and S. Inarta., 2008. **DUSTER** . Aerosol collection in the stratosphere. Memorie della Societa Astronomica Italiana, 79, p.853

[8] Census, BEXUS 7, http://www.stratospheric-census.org/blog-test/

[9] Deshler, T. M. E. Hervig, C. Kröger, D. J. Hofmann, J. M. Rosen, J. B. Liley, 2002. Thirty years of in situ stratospheric aerosol size distribution measurements from Laramie, Wyoming (41°N), using balloonborne instruments, J. Geophys. Res.: Atmospheres 108(D5),

[10] EuroLaunch: **BEXUS User Manual** (2014)

[11] European Cooperation for Space Standardization ECSS: Space Project Management, **Project Planning and Implementation**, ECSS-M-ST-10C Rev.1, 6 March 2009

[12] SSC Esrange: **Esrange Safety Manual**, REA00-E60 , 23 June 2010

[13] European Cooperation for Space Standardization ECSS: Space Engineering, **Technical Requirements Specification**, ECSS-E-ST-10-06C, 6 March 2009

[14] European Cooperation for Space Standardization ECSS, Space Project Management, **Risk Management**, ECSS-M-ST-80C, 31 July 2008

[15] European Cooperation for Space Standardization ECSS: Space Engineering, **Verification**, ECSS-E-ST-10-02C, 6 March 2009

[16] Project Management Institute, **Practice Standard for Work Breakdown Structures – second Edition**, Project Management Institute, Pennsylvania, USA, 2006

[17] Misra et al., 2002

APPENDIX A EXPERIMENT REVIEWS

Preliminary Design Review – PDR

REXUS / BEXUS
Experiment Preliminary Design Review

Flight:	BX18		
Payload Manager:	tbd		
Experiment:	A5-Unibo		
Location:	SSC, Esrange Space Center, Sweden	**Date:**	04 Mar 2014

1. Review Board members

Andreas Stamminger, MORABA
Peter Turner, MORABA
Olle Persson, SSC
Alex Kinnaird, SSC
Simon Mawn, ZARM
Dieter Bischoff, ZARM
Koen deBeule, ESA
Lucio Scomaliero, ESA
Natacha Callens, ESA
Nora Newie, ESA

2. Experiment Team members

Encarnacion Serrano Castillo
Alberto Sodi
Riccardo Lasagni Manghi
Igor Gai

3. General Comments

- Presentation
  - Don't read slides
  - Some text too small
  - Focus on design earlier in presentation
  - Try to get more contact with the audience
- SED
  - Some content (technical data) missing
  - it's version 1.0 (also for change record)
  - put name under "issued by"
  - include bookmarks
  - keep to SED numbering as in guidelines (ch 4...)
  - caption your figures and tables
  - Preface missing
  - If information missing or unclear at the moment, say tbd
  - All chapters should be filled out
  - Keep the document in English
  - Do not change the format of the cover page
  - Too many blank pages
  - Do not copy scientific text verbatim for your scientific introduction, reference all sources.
  - Foundings vs. funding
  - Ensure requirements updates in chapter 2 are copied to chapter 5.
  - Include data sheets of the COTS instruments to be used.

4. Panel Comments and Recommendations

- Requirements and constraints (SED chapter 2)
  - Some requirements to be split up (eh FR3)
  - Should and shall to be used correctly
  - Some are in wrong category, OR2 is mix up between ops and design req.
  - Don't use "survive" in requirements
  - 10m in altitude is hardly to achieve (maybe less precise measurement)
  - Objectives are good
  - Functional requirements may be a little 'wordy' (especially FR1 and FR2)
  - Avoid 'lumping' requirements (FR3), it makes requirement management and verification more difficult.
  - Functional requirements are good and all cover all the important aspects of the experiment.
  - PR8 is an incomplete requirement.
  - DR8 – include the correct pinning of the Amphenol connector in the requirement.

- Mechanics (SED chapter 4.2.1 & 4.4)
  - Experiment components list is missing
  - Use metallic connectors not plastic ones for profiles
  - Fix with glue (esp. for recovery in truck)
  - Need verification (test, analysis or similar) that it can withstand 5g – mention here
  - Might be possible to improve mass and volume
  - Team clarified that no hole in gondola floor required
  - Insulation foam should survive low pressure
  - Optical particle counter might be sensitive to vibrations
  - Think about how you can define and verify level of micro-vibrations introduced by instruments

- Electronics and data management (SED chapter 4.2.2, 4.2.3, 4.5, 4.7, 4.9)
  - Needs more detail for CDR
  - All subsystems should be identified where they are in the box
  - Justify power consumption, do power budget
  - Clarify GPS system that team wants to use (some are limited in altitude and speed – make sure it can do what you need)
  - GPS needs to be open (some systems stop at 18km), eg Novatel
  - Re-think and refine the power system design

- Thermal (SED chapter 4.2.4 & 4.6)
  - Well identified and complete
  - Much of the analysis should rather be in appendix than main document
  - Often some kind of valve needed for aerosol collection – valves have problems with exposure to cold temperatures

- Software (SED chapter 4.8)
  - Make sure software doesn't stop in case no GPS signal is received/stopped
  - Well-designed but implementation missing so far
  - Overall modes (automatic, manual, ground station) are very good
  - Make a decision after a state → a real state machine would be good for your experiment, then you could switch between states (now mainly sequencing)
  - Approach with sequence programme might have a lot of delays (since you only have sequencing machine) – maybe you rather use interrupt programming (of Arduino Mega)
  - Ensure manual mode has a timeout to take it back to autonomous mode.
  - You will experience a gradual descent during float – this should be accounted for in your tolerances for detection of descent (descent rate) and confirmation of float.
  - Define data rates

- Verification and testing (SED chapter 5)
  - Maybe you want to test some of the requirements you only review so far (like water test)
  - T3/T4 thermal test should show how good your calculations are, test in August is too late, do asap

- pumps starting at low pressure is often a problem → test early
- PT3 is good test, call it differently (pump vibration or microvibration test)
- Add column in verification matrix where you correlate to test number

- Safety and risk analysis (SED chapter 3.5)
  - 5 risks with a severity of 5 → classification is wrong (e.g. components missing no 5)
  - Lots of risks missing – more detail needed for CDR
  - Forgot schedule, budget, conflict in team, lack of expertise risks
  - Flight batteries are a risk for recovery (battery fire)

- Launch and operations (SED chapter 6)
  - A lot is missing (timeline, BX interface…)
  - You need to make sure that the particles are actually from atmosphere and not ground
  - Need very clean pumps – needs a lot of work
  - Team wants to use spare filters
  - Have a look at Cass-E SED for tips and ideas on how to keep pumps clean
  - Environment during Launch will be dirty (Hercules, balloon pad)
  - Ascent cleans balloon of dust with goes to gondola = measurements during ascent are from ground
  - Team clarified that Optical Particle Counter is not a real laser more a light – put in SED
  - Team will not sample during descent
  - No flight requirements?

- Organisation, project planning & outreach (SED chapters 3.1, 3.2, 3.3 & 3.4)
  - Pictures for team members would be nice
  - Include a contact phone number for the student team
  - WBS is clear
  - White is hard to read
  - Testing (what) in subsystems in unclear – team clarified it means for assembled experiment
  - add also progress, how far along you are, here we only see what you intend to do when
  - Colours in Gantt chart unclear
  - Map the availability of the team (over the year) to the workload shown in the Gannt chart to be sure you have sufficient resources at the right times Update budget in document
  - Budget for traveling, delivery cost of components, spare components missing
  - Add column of who is paying, so we know what budget you have and what is missing - include everything (even if you get it for free from sponsors)
  - Use tdb instead of –
  - Nothing about outreach in appendix – more information needed (copied or articles, screenshots of websites)
  - Put logo in outreach section (description)
  - Facebook/website additionally also in Italian
  - Website: ZARM logo missing, more pictures, add RXBX section (link to our website, ZARM, SSC etc), include links for the 'Institutional partners'

5. Internal Panel Discussion

- Summary of main actions for the experiment team
  - Detail electronics
  - Need information in chapter 6

- PDR Result: conditional pass

- Next SED version due
  SEDv1.2 on March 24th

Critical Design Review – CDR

BEXUS
Experiment Critical Design Review

Flight:	**BX18**		
Payload Manager:	Simon Mawn		
Experiment:	A5-Unibo		
Location:	ESTEC, Noordwijk, the Netherlands	**Date:**	May 8th 2014

1. Review Board Members

Kristine Dannenberg, SNSB
Alex Kinnaird, SSC
Gunnar Andersson, SSC
Maria Roth, DLR
Simon Mawn, ZARM
Dieter Bischoff, ZARM
Julia Grünhage, ZARM
Nick Panagiotopoulos, ESA
Piero Galeone, ESA
Natacha Callens, ESA
Nora Newie, ESA
Document Review only:
Lucio Scolamiero, ESA

2. Experiment Team Members

Nani Serrano
Danilo Boccadamo
Abramo Ditaranto
Alice Zaccone
Riccardo Lasagni

3. General Comments

- Presentation
  - Reading of the slides a lot
  - Very technical (details) – good but overall concept was missing to understand the detail
- SED
  - Avoid blank pages
  - Introduce acronyms first time you use them
  - Include bookmarks
  - Reduce size of file
  - Some information is in wrong chapters
  - Internal references are not working (maybe problem with pdf-ing as they are blue coloured...)
  - Footer is missing
  - Sometimes you start a new line in the middle of a sentence
  - Very good schematics (colours etc)
  - System levels budgets and according timeline missing
  - Stick to the file naming convention for your CAD models

4. Panel Comments and Recommendations

- Requirements and constraints (SED chapter 2)
  - Very good requirements
  - Think about constraints
  - Software itself should not be redundant, but use redundant data
  - Include a requirement for the BEXUS power interface

- Mechanics (SED chapter 4.2.1 & 4.4)
  - On a good way
  - Design and assembly of each sensor is missing
  - Update manufacturing drawings etc. on teamsite
  - More information on single components is needed
  - Maybe annotate figure 4.1-4.1-1 (experiment overview) with some of the text below it?
  - How will you access the mounting?

- Electronics and data management (SED chapter 4.2.2, 4.2.3, 4.5, 4.7, 4.9)
  - Unclear when you talk about batteries if you mean your own batteries or gondola batteries – specify terms
  - Don't be over-tolerant to failures (battery AND E-Link failure is very unlikely) – better move to single-failure tolerant system (if at all needed – out of scope of BX experiment)
  - Loss of ground communication might be critical – focus on this rather than battery redundancy
  - You should rely on the batteries, a redundancy switching is unnecessary
  - Redundancy makes power system to complicated - consider using a pack of 8 SAFT MP176065 rechargeable cells. This pack will provide 200Wh of energy and can handle currents up to 10A - then use switching regulators to create secondary voltages
  - Team should use batteries within specifications (at -20C you will have 50% of batteries' power), team clarified this was worst case simulation to decide if heaters are necessary
  - 0C would be better for batteries
  - Heavy load on battery gives you less power especially at low temperatures – chosen battery is not suitable for BX (you are on limit of battery's power)
  - Consider adding some high-power DC converters to account for high power needs
  - Remember that your own battery will discharge during countdown (not connected to Hercules umbilical) – team clarifies they have spare battery packages
  - Overview of power consumption (diagram: time - power & consumed energy) should be included (easier for you to see when you have highest currents)
  - Include a simple 'quick glance' diagram for the power supply so we can see what includes your own batteries, what is powered from BEXUS and how
  - A timeline of not only power but whole mission (data rates, buffers, transmissions, software….) is very helpful
  - No BEXUS power required included in 'electrical interface' but mentioned in 'power system'
  - P74 a 3 wheel-diode is missing over relay
  - You should have recovery diode in parallel to the relays you use (as seen on presentation)
  - Don't use melting fuses – use current-limiting switch instead (e.g. Infineon series ITS414x)
  - Take care of grounding – include grounding diagram
  - Compatibility between currents and voltages of sub-units should be considered
  - Is the Ethernet shield compatible with fixed IP addresses used on BEXUS? - Verify compatibility and how IP address is configured

- Thermal (SED chapter 4.2.4 & 4.6)
  - Very good thermal design
  - Team clarified they used a static simulation
  - Airflow should be considered as a loss of heat too – consider adding to simulation

- Software (SED chapter 4.8)
  - How/When do you time-tag data after a loss of data? Think about it
  - System introduction should be added to beginning of chapter
  - Team uses sequence flow programme – Is this the right approach? Are you sure you can take measurements in every state?
  - Need timer event which pulls Ethernet port (interrupt timing routine through a server)
  - You need to use more events and interrupt possibilities of Arduino
  - Do low level routines for lab view work together with Ethernet shield of Arduino? - **Simon to email possible options to team**
  - Figure 4.8-3 – Climb state: 'check altitude' should have a decision (i.e. climb rate constant or <x etc)

- Verification and testing (SED chapter 5)
  - Good chapter
  - Explain 'v' of the test column in legend
  - A lot of full system tests are very late in schedule – do earlier

- Show subsystem and component tests in document
- PT2 is very important test – do soon
- For full verification of operation under flight conditions temperatures tests should be done in a low pressure environment - team still looking for institute with thermal-vacuum chamber
- Shock is hard to verify by analysis
- Drop Test: think about ground preparation, you don't want hard impact

- Safety and risk analysis (SED chapter 3.5)
  - Add numbers to risks
  - risks of missing fundings/budget missing
  - risks of shipping delay of experiment to Esrange missing

- Launch and operations (SED chapter 6)
  - Chapter 4 and 6 experiment summary tables must be same – team already changed it
  - Team shall be supplied with laser operation guidelines by SSC and be aware of the requirements for handling and shipping
  - Team doesn't want to open laser – then considered class 1 – this wouldn't need approval of Swedish authorities
  - When/how experiment will be turned off not considered yet by team – recommendation is to switch off by telecommand before descent
  - If you need advance notice before cut-down, tell how much
  - Cleaned room, but no clean room available (ca 1km away from balloon preparation area)
  - Specify what kind of clean room you need
  - Discuss with SSC about ultra-sonic bath – SSC probably doesn't have it
  - Bring your own cleaning solution
  - Access to gondola after FCT is very limited (1 person at a time under SSC surveillance)
  - Remove all RBFs at pick-up, remove SU inlet RBF at line-up
  - Gondola is lifted after pick-up the whole time
  - Team has an arm-key for RBFs – make sure you have it in a place where you find it
  - Be sure to have a check list and a place for the RBFs and key clearly labelled (a case with silhouettes is a good idea).
  - Recovery actions required? – SU protection back on – to be included in SED
  - Include flight requirements (float duration, height, day flight or night flight) in chapter 6

- Organisation, project planning & outreach (SED chapters 3.1, 3.2, 3.3 & 3.4)
  - Chapter improved a lot since PDR
  - Add new members in join space even if you can't link them to team there
  - Man power very clear
  - If helpful for you – include more details in WBS
  - Add legend to Gantt Chart
  - Travel money for non-sponsored students is not enough
  - Budget deficit unclear – show clearly what is lacking
  - Good outreach
  - Facebook maybe in 3 languages? Show more status updates (small things that happen, some pictures etc..)
  - Website translation still on-going
  - "Sponsors and Partners" on website are wrong - program sponsors are SNSB, DLR and ESA, those are no partners! (SNSB logo more important than SSC, don't include MORABA) – maybe do this section more general
  - Wrong link to ZARM on website

- Others
  - Lessons learned are good for this stage of project
  - SSC makes balloon GPS data available to all teams post-flight

5. Internal Panel Discussion

- Summary of main actions for the experiment team
  - Power system needs a different design (capacity problems)
  - Redundancy drives design – not good - reconsider
  - More system level concept (redundancy and power concept) to be shown
  - Mechanical: some information lacking

- CDR Result: conditional pass
- **SEDv2.1** due on **May 28th 2014**

Integration Progress Review – IPR

Experiment Acceptance Review - EAR

APPENDIX B OUTREACH AND MEDIA COVERAGE

Choice of Logo

A5-Unibo Logo is the signature of the experiment and one of the most valuable assets because it is a single element that symbolizes the whole project. We tried to design it simple and unique.

A5-Unibo decided to choose the circular geometry as REXUS/BEXUS Logo and as most of previous experiments of the program.

We decided to choose a single icon or image to represent the whole experiment: a cloud. This regards our primary objective that is to study the correlation between different atmospheric parameters in order to better understand the clouds formation and its relation with climate change.

We chose blue and grey to model a real sky and then we choose red for the frame and yellow for the name because they are very bright colours that would contrast with the base design in order to highlight the name of the team (in yellow), the program that we belong to and institution where we come from (in white over red frame).

We chose a lightening for the letters because it is an element very linked to the clouds that also shall represent the strength and determination to face the difficulties during the project.

8.2-1 Preliminary Logo

8.2-2 Final Logo

Pubblications and other media

- La Repubblica Newspaper (22/01/14)
  - http://ricerca.repubblica.it/repubblica/archivio/repubblica/2014/01/22/ingegneri-in-svezia-per-studiare-la-vita.html
- Other Regional and National Newspapers are interested in us.
- Università di Bologna Magazine is also interested in us.
- http://www.magazine.unibo.it/archivio/2014/05/23/a5-l2019esperimento-scientifico-selezionato-dall2019esa

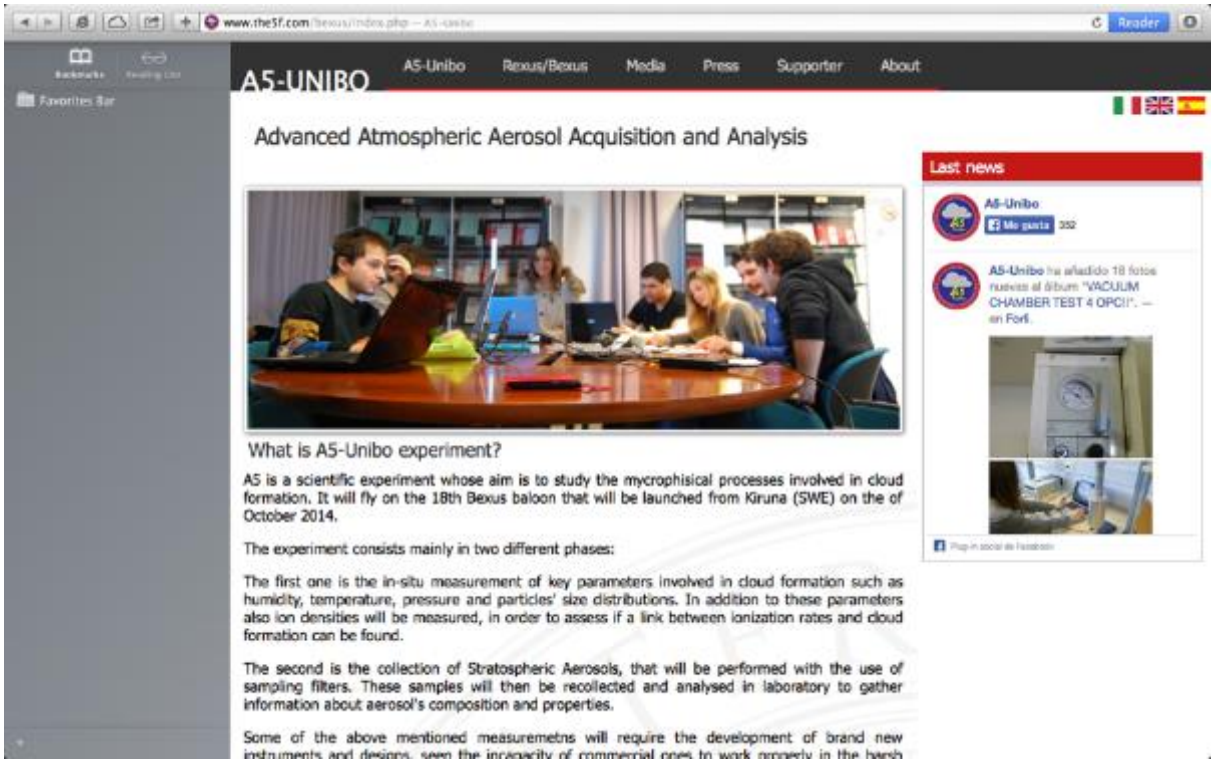
Educational Activities

- Aerospace Engineering Faculty Open Days (03/04/2014)
  - http://corsi.unibo.it/Laurea/IngegneriaAerospaziale/Eventi/2014/02/open-day-sede-di-forl.htm
- Elementary School Activities (60 children) in Flight Mechanics Laboratory (14/04/14)
  - Presentation to the Advance Science Institute of the University of Bologna (July-2014)

Other Activities

- Presentation to CNA (Confederazione Nazionale del Artegianato) in order to show the companies in Emilia Romagna Region what A5-Unibo is performing
- Contact other companies and institutions that could be possibly interested as ambiental foundations that has as main goals the prevention in the environmental field, to protect the health of the population and promote sustainability.
- Website in three languages: English, Italian and Spanish

8.2-3 Other Outreach


A5-UNIBO
A5-Unibo
Rexus/Bexus
Media
Press
Supporter
About
Advanced Atmospheric Aerosol Acquisition and Analysis
Last news
What is A5-Unibo experiment?
A5 is a scientific experiment whose aim is to study the mycrophisical processes involved in cloud formation. It will fly on the 18th Bexus baloon that will be launched from Kiruna (SWE) on the of October 2014.
The experiment consists mainly in two different phases:
The first one is the in-situ measurement of key parameters involved in cloud formation such as humidity, temperature, pressure and particles' size distributions. In addition to these parameters also ion densities will be measured, in order to assess if a link between ionization rates and cloud formation can be found.
The second is the collection of Stratospheric Aerosols, that will be performed with the use of sampling filters. These samples will then be recollected and analysed in laboratory to gather information about aerosol's composition and properties.
Some of the above mentioned measuremetns will require the development of brand new

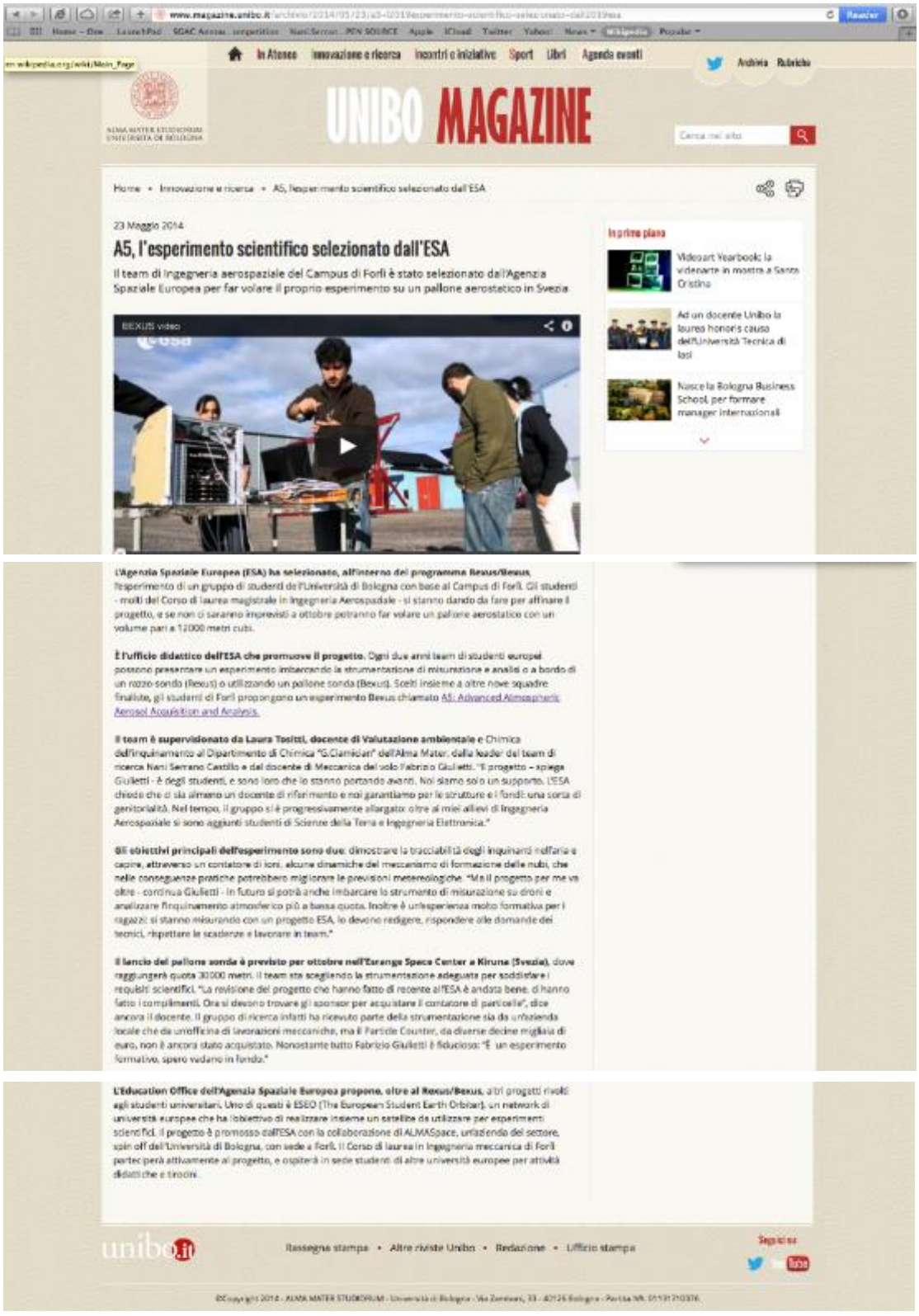
8.2-4 A5-Unibo Website

8.2-5 A5-Unibo Facebook

8.2-6 A5-Unibo Twitter

la Repubblica.it
Archivio
Home
Pubblico
Economia&Finanza
Sport
Spettacoli
Cultura
Motori
Viaggi
Moda
Casa
Salute
Meteo
Lavoro
Annunci
MASCHIO
MASCHIO TI PORTA AL 7Cielo
Ingegneri in Svezia per studiare la vita delle nuvole
L' AGENZIA spaziale europea (Esa) ha selezionato il loro esperimento, che sarà eseguito in Svezia su un pallone sonda. Servirà a capire meglio il fenomeno di formazione delle nuvole. L' annuncio è arrivato quasi inatteso. E il gruppo premiato nove studenti di ingegneria aerospaziale e scienze ambientali e una dottoranda in fisica dell' atmosfera - guidato da la dottoranda Nani Serrano Castillo, si è messo già al lavoro. L' esperimento proposto dal team forlivese dell' Alma Mater, sviluppato con il supporto del laboratorio di Meccanica del volo e dal dipartimento di Chimica, sarà condotto a bordo di un pallone stratosferico che sarà lanciato a ottobre presso il centro spaziale svedese di Kiruna. «L' obiettivo è aumentare la conoscenza dei fenomeni legati al ciclo atmosferico dell' acqua», spiegano i giovani ricercatori. Una strada per migliorare l' accuratezza delle previsioni meteo e per raffinare le tecniche di inseminazione delle nuvole per contrastare gli effetti dei climi sempre più aridi. «Una bella soddisfazione», commenta Fabrizio Giulietti, il ricercatore di Meccanica del volo che segue il progetto. «Siamo un piccolo gruppo ma facciamo belle cose. È per gli studenti poter condividere un progetto di questa portata è importante». L' Esa ha selezionato solo quattro esperimenti nell' ambito del programma Bexus, tra questi quello del team A5-Unibo che ha aperto una pagina Facebook. E lancia un appello per i fondi. «Cerchiamo sponsor per coprire parte delle spese del progetto».
TOPIC CORRELATI
PERSONE
ENTI E SOCIETÀ
LUOGHI
TIPO
articolo

8.2-7 A5-Unibo La Repubblica



UNIBO MAGAZINE

Home • Innovazione e ricerca • A5, l'esperimento scientifico selezionato dall'ESA

23 Maggio 2014

A5, l'esperimento scientifico selezionato dall'ESA

Il team di Ingegneria aerospaziale del Campus di Forlì è stato selezionato dall'Agenzia Spaziale Europea per far volare il proprio esperimento su un pallone aerostatico in Svezia

In prima piano

Videoart Yearbook: la videoarte in mostra a Santa Cristina

Ad un docente Unibo la laurea honoris causa dell'Università Tecnica di Iasi

Nasce la Bologna Business School, per formare manager internazionali

BEXUS video

L'Agenzia Spaziale Europea (ESA) ha selezionato, all'interno del programma Rexus/Bexus, l'esperimento di un gruppo di studenti de l'Università di Bologna con base al Campus di Forlì. Gli studenti - molti del Corso di laurea magistrale in Ingegneria Aerospaziale - si stanno dando da fare per affinare il progetto, e se non ci saranno imprevisti a ottobre potranno far volare un pallone aerostatico con un volume pari a 12000 metri cubi.

È l'ufficio didattico dell'ESA che promuove il progetto. Ogni due anni team di studenti europei possono presentare un esperimento imbarcando la strumentazione di misurazione e analisi a bordo di un razzo-sonda (Rexus) o utilizzando un pallone sonda (Bexus). Scelti insieme a otto nove squadre finaliste, gli studenti di Forlì propongono un esperimento Bexus chiamato A5: Advanced Atmospheric Aerosol Acquisition and Analysis.

Il team è supervisionato da Laura Tositti, docente di Valutazione ambientale e Chimica dell'inquinamento al Dipartimento di Chimica "G.Ciamician" dell'Alma Mater, dalla leader del team di ricerca Nani Serrano Castillo e dal docente di Meccanica del volo Fabrizio Giulietti. "Il progetto – spiega Giulietti - è degli studenti, e sono loro che lo stanno portando avanti. Noi siamo solo un supporto. l'ESA chiede che ci sia almeno un docente di riferimento e noi garantiamo per le strutture e i fondi: una sorta di genitorialità. Nel tempo, il gruppo si è progressivamente allargato: oltre ai miei allievi di Ingegneria Aerospaziale si sono aggiunti studenti di Scienze della Terra e Ingegneria Elettronica."

Gli obiettivi principali dell'esperimento sono due: dimostrare la tracciabilità degli inquinanti nell'aria e capire, attraverso un contatore di ioni, alcune dinamiche del meccanismo di formazione delle nubi, che nelle conseguenze pratiche potrebbero migliorare le previsioni meteorologiche. "Ma il progetto per me va oltre - continua Giulietti - In futuro si potrà anche imbarcare lo strumento di misurazione su droni e analizzare l'inquinamento atmosferico più a bassa quota. Inoltre è un'esperienza molto formativa per i ragazzi: si stanno misurando con un progetto ESA, lo devono redigere, rispondere alle domande dei tecnici, rispettare le scadenze e lavorare in team."

Il lancio del pallone sonda è previsto per ottobre nell'Esrange Space Center a Kiruna (Svezia), dove raggiungerà quota 30000 metri. Il team sta scegliendo la strumentazione adeguata per soddisfare i requisiti scientifici. "La revisione del progetto che hanno fatto di recente all'ESA è andata bene, di hanno fatto i complimenti. Ora si devono trovare gli sponsor per acquistare il contatore di particelle", dice ancora il docente. Il gruppo di ricerca infatti ha ricevuto parte della strumentazione sia da un'azienda locale che da un'officina di lavorazioni meccaniche, ma il Particle Counter, da diverse decine migliaia di euro, non è ancora stato acquistato. Nonostante tutto Fabrizio Giulietti è fiducioso: "È un esperimento formativo, spero vederlo in fondo."

L'Education Office dell'Agenzia Spaziale Europea propone, oltre ai Rexus/Bexus, altri progetti rivolti agli studenti universitari. Uno di questi è ESEO (The European Student Earth Orbiter), un network di università europee che ha l'obiettivo di realizzare insieme un satellite da utilizzare per esperimenti scientifici. Il progetto è promosso dall'ESA con la collaborazione di ALMASpace, un'azienda del settore, spin off dell'Università di Bologna, con sede a Forlì. Il Corso di laurea in Ingegneria meccanica di Forlì partecipera attivamente al progetto, e ospiterà in sede studenti di altre università europee per attività didattiche e tirocini.

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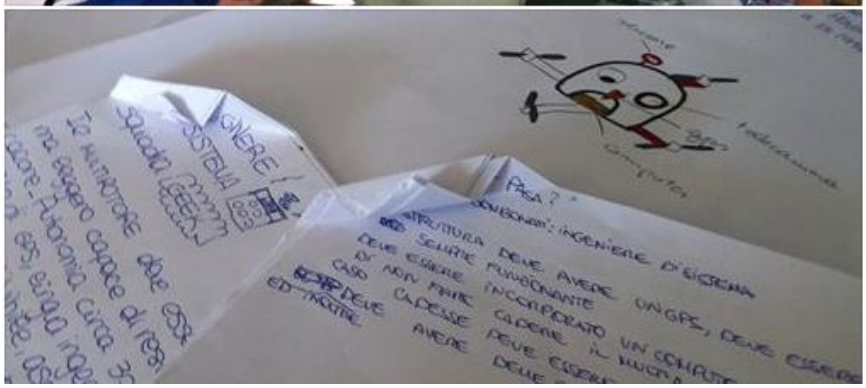
8.2-8 A5-Unibo - Unibo Magazine

A5-Unibo
Publicado por Nani Serrano Castillo [?] · 14 de abril · Editado

Today 45 students from SCUOLA MEDIA STATALE COVA-LANZONI Faenza (Italy) have visited Flight Mechanics Laboratory and they have learnt how A5Unibo works within BEXUS Programme. They have also been divided in teams and everyone has become an engineer for two hours. Then they have shown the proposals of different experiments with their requirements, in the same way as we did for PDR.

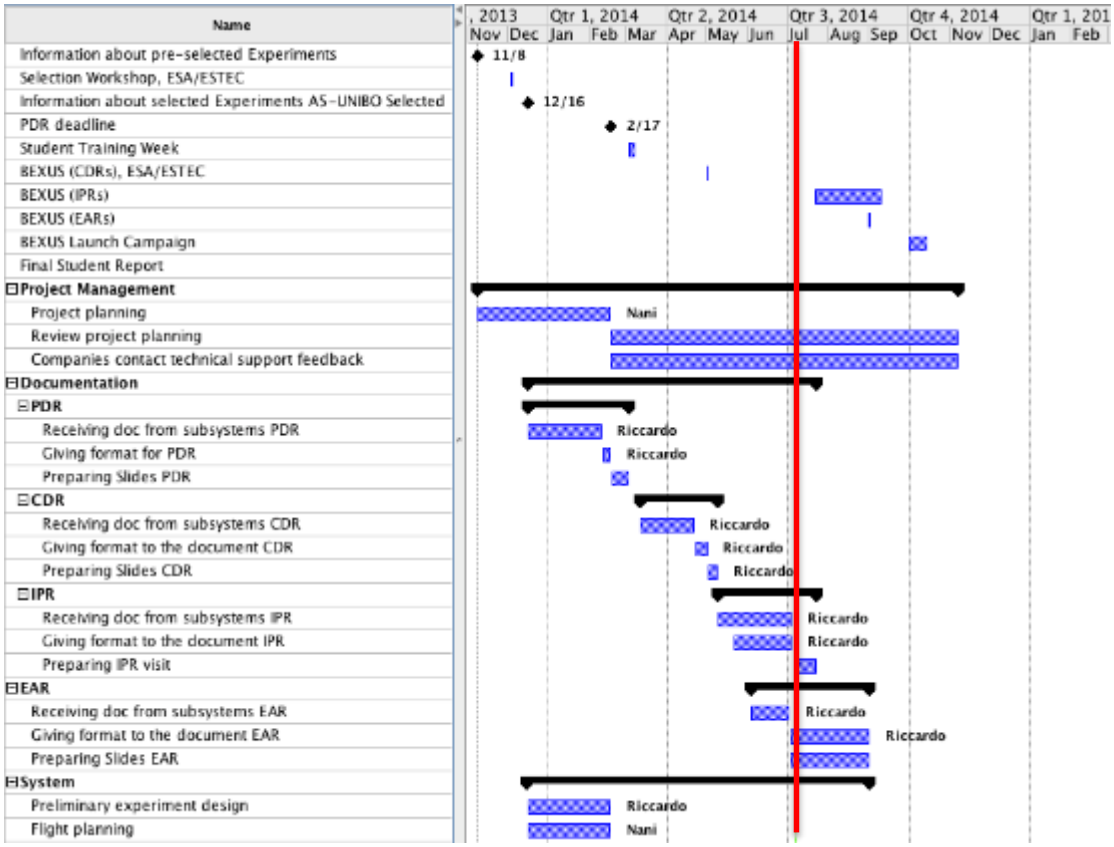
Oggi 45 studenti della SCUOLA MEDIA STATALE COVA-LANZONI Faenza (Italia) hanno visitato il Laboratorio di Meccanica del Volo, hanno imparato come A5Unibo lavora nell'ambito del programma BEXUS. Si sono divisi in gruppi e ognuno é diventato ingegnere per due ore. In seguito hanno illustrato le loro proposte ai loro compagni, descrivendo i diversi esperimenti e relativi requisiti, così come A5Unibo ha fatto per la PDR.

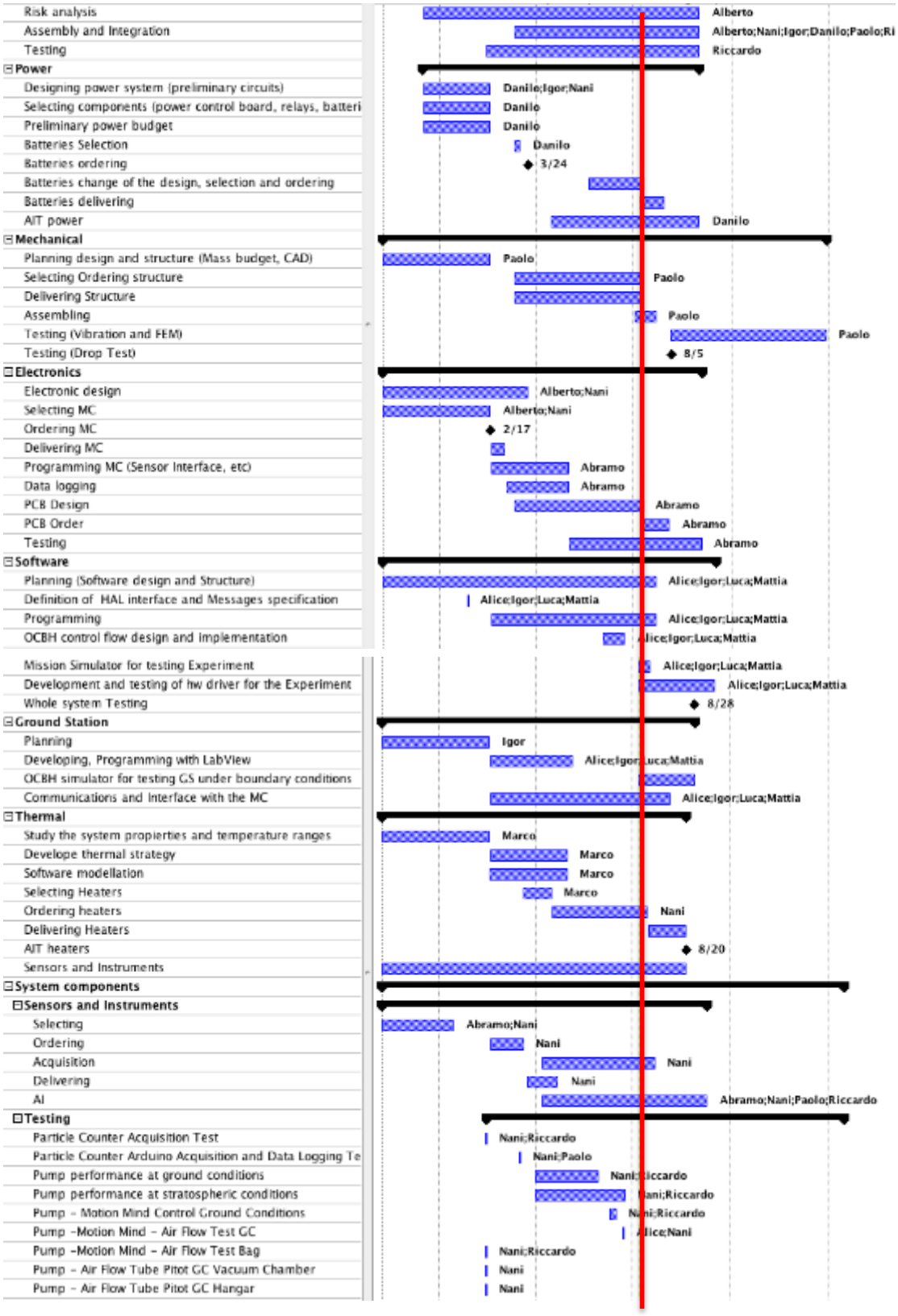
Hoy 45 estudiantes de SCUOLA MEDIA STATALE COVA-LANZONI Faenza (Italia) han visitado el Laboratorio del Mecánica del Vuelo y han aprendido cómo A5Unibo trabaja en en programa BEXUS. Se han dividido en grupos y cada uno de ellos se ha convertido en ingeniero durante dos horas. Después han mostrado sus propuestas de los distintos experimentos y los requisitos, del mismo modo que nosotros hicimos para la PDR.



8.2-9 A5-Unibo - Elementary School Avtivities

APPENDIX C GANTT CHART




Risk analysis
Assembly and Integration
Testing
Power
Designing power system (preliminary circuits)
Selecting components (power control board, relays, batteri
Preliminary power budget
Batteries Selection
Batteries ordering
Batteries change of the design, selection and ordering
Batteries delivering
AIT power
Mechanical
Planning design and structure (Mass budget, CAD)
Selecting Ordering structure
Delivering Structure
Assembling
Testing (Vibration and FEM)
Testing (Drop Test)
Electronics
Electronic design
Selecting MC
Ordering MC
Delivering MC
Programming MC (Sensor Interface, etc)
Data logging
PCB Design
PCB Order
Testing
Software
Planning (Software design and Structure)
Definition of HAL interface and Messages specification
Programming
OCBH control flow design and implementation
Mission Simulator for testing Experiment
Development and testing of hw driver for the Experiment
Whole system Testing
Ground Station
Planning
Developing, Programming with LabView
OCBH simulator for testing GS under boundary conditions
Communications and Interface with the MC
Thermal
Study the system propierties and temperature ranges
Develope thermal strategy
Software modellation
Selecting Heaters
Ordering heaters
Delivering Heaters
AIT heaters
Sensors and Instruments
System components
Sensors and Instruments
Selecting
Ordering
Acquisition
Delivering
AI
Testing
Particle Counter Acquisition Test
Particle Counter Arduino Acquisition and Data Logging Te
Pump performance at ground conditions
Pump performance at stratospheric conditions
Pump - Motion Mind Control Ground Conditions
Pump -Motion Mind - Air Flow Test GC
Pump -Motion Mind - Air Flow Test Bag
Pump - Air Flow Tube Pitot GC Vacuum Chamber
Pump - Air Flow Tube Pitot GC Hangar
Alberto
Alberto;Nani;Igor;Danilo;Paolo;Ri
Riccardo
Danilo;Igor;Nani
Danilo
Danilo
Danilo
3/24
Danilo
Paolo
Paolo
Paolo
Paolo
8/5
Alberto;Nani
Alberto;Nani
2/17
Abramo
Abramo
Abramo
Abramo
Abramo
Alice;Igor;Luca;Mattia
Alice;Igor;Luca;Mattia
Alice;Igor;Luca;Mattia
Alice;Igor;Luca;Mattia
Alice;Igor;Luca;Mattia
Alice;Igor;Luca;Mattia
8/28
Igor
Alice;Igor;Luca;Mattia
Alice;Igor;Luca;Mattia
Marco
Marco
Marco
Marco
Nani
Nani
8/20
Abramo;Nani
Nani
Nani
Nani
Abramo;Nani;Paolo;Riccardo
Nani;Riccardo
Nani;Paolo
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Alice;Nani
Nani;Riccardo
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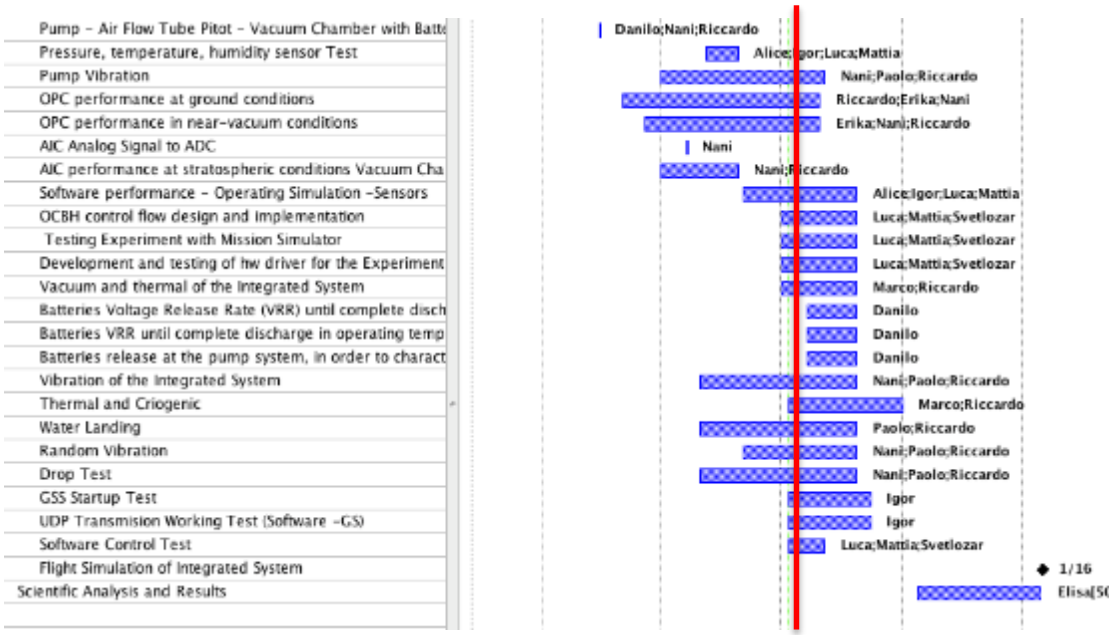
Nani



Gantt Chart has been updated according to the needs of the project and the delays due to the purchasing and delivering of the components and instruments.

Red line: current Status

Green line: progress line

APPENDIX D THERMAL DESIGN DETAILS

Thermal exchanges

In this section, the exchanged thermal fluxes used for the Thermal Analysis of section 4.6 are listed and described.

Radiation

- Thermal input due to the solar radiation. The direct solar flux, also called solar irradiance, is inversely proportional to the square of the distance to the Sun. The assumed value for the solar constant is:

$J_s = 1367 \quad W \times m^{-2}$

The solar input q_{SUN} for each *i*-node can be calculated with the following equation:

$$q_{SUN} = A_i F_{i \to SUN} J_s \cdot a_{s_i}$$

a_{s_i} is the absorption coefficient of the spacecraft surfaces at 0.5 µm wavelength.

The view factors have to be determined with the following relation:

$$F_{i \to SUN} = \frac{1}{\pi A_i} \int_A \int_B \frac{\cos\varphi_i \cos\varphi_{SUN}}{d^2} dA_i dA_{SUN}$$

- Thermal input due to the albedo radiation, which is the fraction of the solar radiation that is reflected by the planet's surface, is highly dependent on the surface's optical properties. To a first approximation, the planet can be considered a Lambertian body, therefore the radiation is uniformly reflected back into space in all directions.

  The albedo radiation can be assumed to have the same spectrum as the solar radiation, therefore the maximum of the spectrum corresponds to 0.5 µm (visible wavelengths); the actual albedo radiation spectrum can change depending on the properties of the planet's surface, since different materials can lead to absorption in certain wavelength bands.

  The fraction of the solar radiation which is reflected is:

  $$q_{ALBEDO} = r A_i \cdot J_s \cdot F_{i \to ALBEDO} \cdot a_{s_i}$$

  Where ρ (or a) is the bond albedo coefficient at 0.5 µm.

- Thermal input due to the planetary radiation, which depends on the temperature of the planet's surface and the mutual position of the spacecraft and the planet.

  $$q_{PLANET} = s A_i \left(T_{j,PLANET}^4 - T_i^4 \right) F_{i \to j} e_i \cdot e_{PLANET}$$

  e_i is the absorption coefficient of the surface for a $4 \mu m$ wavelength.

e_{PLANET} is the emissivity coefficient of the planet's surface at the same wavelength.

- Thermal output towards the sky background at 3-4 K temperature, which is assumed to behave like a black body.

  The heat flux q_{SKY} emitted by the node *i* towards the sky background is given by the following relation:

  $$q_{SKY} = s A_i \left(T_{SKY}^4 - T_i^4\right) F_{i \to SKY} \cdot e_i$$

  By the knowledge of all other view factors (previously calculated), the view factor $F_{i \to SKY}$ is computed as follow:

- Heat exchanges between internal nodes

  $$q_i = -A_i G_i (1 - F_{i-i}) + \sum_{j=1,\ j \neq i}^{n} A_j F_{i-j} G_j$$

  Where G_j is the radiance and has been calculated solving the following linear system:

  $$A_i G_i = A_i J_i + r_i \sum_{j=1}^{n} A_j F_{ij} G_j$$

  Where: $J_i = \varepsilon_i \sigma T_i^4$ and $r_i = 1 - \varepsilon_i$

Conduction

The conductive heat exchange between adjacent nodes is given by the following equation:

$$dq_{cond,i} = -\lambda \cdot dA_i \frac{T_i - T_j}{s}$$

Convection

Heat exchange by convection between adjacent nodes is given by the following relation:

$$dq_{conv,i} = \alpha_{conv} dA_i \left(T_j - T_i\right)$$

Nodal breakdown, bulk and thermo-optical properties

Table 8.2-1 Node numbering and architecture

Node number	Description	Notes
BOUNDARY NODES		
B_SKY	Sky background	
B_PLANET	Planet	
B_Air	External air	

DIFFUSIVE NODES		
D1	Insulating wall	External side
D2	Insulating wall	Internal upper side
D3	Insulating wall	Internal medium side
D4	Insulating wall	Internal bottom side
D5	Internal air	Upper side
D6	Medium plate	Upper side
D7	Medium plate	Bottom side
D8	Internal air	Bottom side
D9	Support plate	Upper side
D10	Support plate	Bottom side
D11	Gondola deck	/
D12	Batteries	/
D13	Other instruments	/
Node number	**Description**	**Notes**

Table 8.2-2 Node Properties

Node	Name	Material	α_S	ε_{IR}	Node
1	Insulating wall – external	Multilayer	0.12	0.035	1
2	Insulating wall – internal up	Polyurethane foam	/	0.55	2
3	Insulating wall – internal medium	Polyurethane foam	/	0.55	3
4	Insulating wall – internal down	Polyurethane foam	/	0.55	4
5	Internal air – up	/	/	/	5
6	Medium plate – up	Al6061 – T6	/	0.08	6
7	Medium plate – down	Al6061 – T6	/	0.08	7
8	Internal air – down	/	/	/	8
9	Support plate – up	Al6061 – T6	/	0.08	9
10	Support plate – down	Al6061 – T6	/	/	10
11	Gondola deck	Al6061 – T6	0.24	0.08	11
12	Batteries	/	/	0.85	12
13	Other instruments	/	/	0.85	13

Table 8.2-3 List of materials

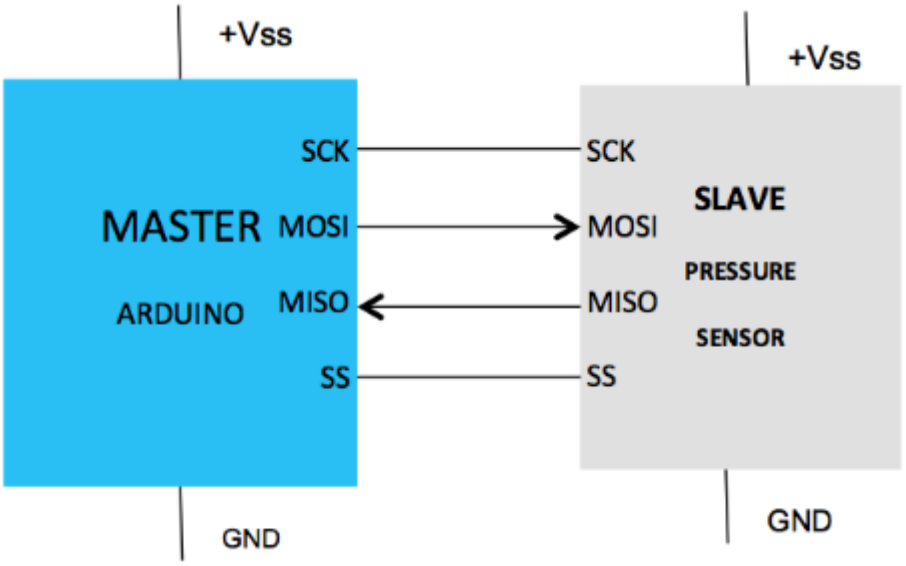
Material	ρ[kg/m^3]	c_P [J/(kg K)]	λ [W/(mK)]
Al6061 – T6	2700	920	175
Polyurethane foam	43	1458	0.023

APPENDIX E COMMUNICATION PROTOCOLS

SPI

The “Serial Peripheral Interface” (SPI) is a synchronous serial data bus. The communication is established between a Master, that will be the microcontroller, and a Slave, that in our case will be the SPI sensors. Data can travel in both directions at the same time. To allow synchronous data transmission, the SPI bus uses four wires. They are called:

- MOSI – Master-out, Slave-in. This line carries data from our Arduino to the SPI-controlled device(s);
- MISO – Master-in, Slave out. This line carries data from the SPI-controlled device(s) back to the Arduino;
- SS – Slave-select. This line tells the device on the bus we wish to communicate with it. Each SPI device needs a unique SS line back to the Arduino;
- SCK – Serial clock.



In Arduino Mega 2560 the pins dedicated to these four wires are:

50 for MISO, 51 for MOSI, 52 for the SCK and SS is usually choose any other pin for SS.

When the SS line is activated (LOW) we have communication between Master (Arduino) and Slave (sensor).The data are transmitted one byte each time through the line MOSI and line MISO, SCK synchronizes the operations.

Each byte contains 8 bits that representing a binary number with a value of between zero and 255. So 2 bytes are enough to represent the sensor output. In the data transmission we need to know how byte is send at first: MSB (most significant bit) or LSB (least significant bit) .

The way to send data is specific for each sensor and datasheet shows how it happens.

SPI						
	MISO	MOSI	SCK	SS		+Vss
Pressure Sensor	50	51	52	38		3,3V
Ethernet Shield	50	51	52	10	4	5V

SPI ARDUINO LIBRARY

Arduino provides a library for SPI connections.

The library is <SPI.h> and the functions that we use are:

- *SPI.begin()* : activate SPI bus
- *SPI.setBitOrder(MSBFIRTS)* or *SPI.setBitOrder(LSBFIRTS)* : says which byte is send at first, MSB or LSB
- *SPI.transfer(value)* : send one byte data

SS line for the specific device has to activate at the moment of data transfer so SS line has to be activated at the first digitalWrite(SS,LOW) an deactivated digitalWrite(SS,HIGH) at the end.

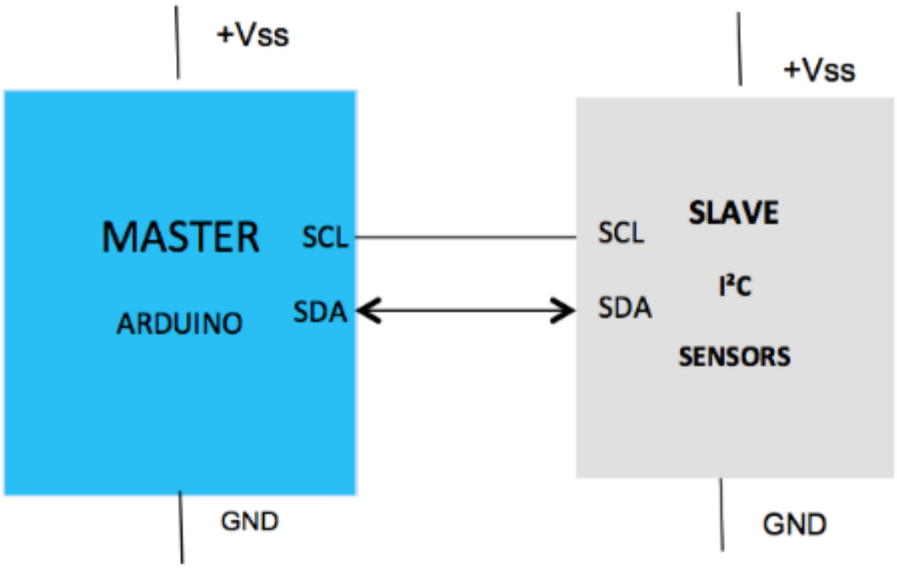
I²C

I²C (Inter-Integrated Circuit) is a master serial single-ended computer bus.

I²C uses only two bidirectional lines :

- Serial Data Line (SDA)
- Serial Clock Line (SCL)

SDA is the unique line used for data transfer in both directions.



The Arduino Mega 2560 uses PIN 20 for SDA and 21 for SCL.

The sensor is designed to work as a Slave and it will respond to request from the Master device (Arduino). The communication starts with the Master that sends a byte containing the specific address sensor (7 bits) plus a bit for the request: read(1) or write (0) . Consequently the Slave sends an ACK and executes the command. The SCL synchronizes the operations.

The sensor sends a byte each time and 2 bytes are enough for sensor output. The datasheets tell if it is send at first MLB or LSB.

I2C			
	SDA	SCL	+Vss
AIC I(+) , AIC I(-) (analogic)-->ADC	20	21	5V
Humidity Sensor	20	21	5V

I²C ARDUINO LIBRARY

Arduino provides a library for I²C connections.

Before calling the function the address device of 7 bit has to be setted.

The library is <Wire.h> and the functions that we use are:

- *Wire.begin()* : activate I²C bus;

- *Wire.requestFrom(address,num_bytes*) : used by the master to request a certain number of bytes from a slave device ;
- *Wire.available()* : returns the number of bytes for retrieval with Wire.read() ;
- *Wire.read()* : reads a byte that was transmitted from a slave device to a master after a call to requestFrom().

ONE WIRE

One Wire is a digital serial communication that uses only one line to transfer data.

One Wire sensor uses any din digital pin of Arduino.

DIGITAL PIN		
	PIN	+Vss
Temperature Sensor	34	5V

ONE WIRE LIBRARY

- *OneWire myWire(pin)* : create the OneWire object, using a specific pin.
- *myWire.search(addrArray)* : Search for the next device. The addrArray is an 8 byte array. If a device is found, addrArray is filled with the device's address and true is returned. If no more devices are found, false is returned.
- *myWire.reset_search()* : begin a new search. The next use of search will begin at the first device.
- *myWire.reset():* reset the 1-wire bus. Usually this is needed before communicating with any device.
- *myWire.select(addrArray): s*elect a device based on its address. After a reset, this is needed to choose which device you will use, and then all communication will be with that device, until another reset.
- *myWire.write(num)*: write a byte
- *myWire.read()*: read a byte
- *myWire.crc8(dataArray, length)* : compute a CRC check on an array of data

UART

The UART (Universal Asynchronous Receiver/Transmitter) is an asynchronous serial data bus.

UART communication has two line for exchange data: transmitting line and reciving line.

The Arduino Mega has four serial ports:

Serial0 on pins 0(RX0) and 1(TX0),

Serial1 on pins 19 (RX1) and 18 (TX1),

Serial2 on pins 17 (RX2) and 16 (TX2),

Serial3 on pins 15 (RX3) and 14 (TX3).

UART			
	RX	TX	+Vss
LOAC	RX1	TX1	External
Pump Motor Controller	RX2	TX2	External
SD	RX3	TX3	5V
GPS	RX0 0	TX0 1	3,3V

UART LIBRARY

The UART communication uses the library <Serial.h>

The functions used are :

- Serial.begin(9600) : sets the data rate in bits per second (baud rate);

- Serial.available() : get the number of bytes (characters) available for reading from the serial port.
  This is data that's already arrived and stored in the serial receive buffer (which holds 64 bytes).

- Serial.read(), Serial1.read() , Serial2.read() ,Serial3.read() : reads incoming serial data.